Project Report

CREDA

Canada/Yukon
Conservation and
Renewable Energy
Demonstration Agreement

Towards Energy Self Sufficiency in the North:

Energy Conservation and Forest Biomass

Symposium held in
association with
the 34th Alaska
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Welcoming Address to

Northern Energy Issues Symposium

Pat Fraser
Director
Energy Branch
Government of Yukon

Good Morning ladies and gentlemen, Mr. Lang. It is an honour to welcome you to this symposium on northern energy issues. The theme will focus on the question of controlling energy demand through conservation measures and one energy supply alternative that has substantial potential in the north - biomass. We look forward to gaining further insight into the long term contribution of these activities to the north's energy situation, from the presentations that we will hear over the next two days.

I would like to take this opportunity to introduce the moderators for the upcoming sessions. Barry Brickman is the senior advisor of northern development with the federal Department of Indian Affairs and Northern Development, Barry will chair the session on construction types and new standards.

Graeme Bethell of Bethell Management and co-chair of the symposium, will moderate the session on community energy conservation projects.

Leading off the retrofit options session is Mel Orecklin from Energy, Mines and Resources, Canada. Mel is the energy project engineer in the Yukon Conservation and Renewable Energy Office.

Barbara Summers is the Director of the Yukon Conservation and Renewable Energy Office. Barbara recently moved to EMR from the Energy Division of the National Research Council. She will be chairing the four sessions tomorrow on energy from forest biomass.

I would like to thank David Arseneault and Graeme Bethell for their work in putting this symposium together. If you have any questions about the symposium ask these 2 gentlemen. My name is Pat Fraser and I am the Director of the Energy Branch in the Yukon Department of Economic Development. I will be chairing the first session this morning on marketing energy conservation.

The energy costs of running a business or maintaining a home have become a very significant component in economic activity in Yukon. The Government of Yukon has long recognized that energy and its supply and consumption patterns are crucial factors in the development of a northern economy. It is for this reason, that our Energy Branch is located within the Department of Economic Development.

It is now my pleasure to introduce to you the Minister of Economic Development with the Government of Yukon, Mr. Dan Lang.

Pat Fraser
Director
Energy Branch

OPENING ADDRESS TO THE CONSERVATION/BIOMASS SYMPOSIUM

The Hon. Dan Lang
Minister of Economic Development
Government of Yukon

Ladies and gentlemen, good morning. I would like to wish all of you a warm welcome to Whitehorse and to Yukon.

I am very pleased to be able to address the opening of this symposium. As a Minister of Economic Development in the Yukon Government, it is not a coincidence that one of the sections of my department is the Energy Branch. The Yukon Government has long recognized that energy and its supply and consumption patterns are crucial factors in the development of a northern economy.

For the past ten years the excessive costs of oil have been a millstone around the neck of our economy. As the prices have risen our advantages in the world marketplace have been eroded. Not only have our exports been severely reduced because of the costs to produce and transport them, but our imports have skyrocketed in price thus reducing our standard of living and cutting into our buying power. Homeowners, small business and industry have suffered together.

The government of Yukon is in the process of critically appraising the alternatives available to us and looking for ways to develop those alternatives. The focus of our attention has been energy conservation and renewable sources of energy. In the past two years we have undertaken 20 conservation and renewable energy demonstrations and have provided energy audits to over 10 per cent of our businesses and institutions.

This symposium represents a unique opportunity for northerners to examine the crucial issue of energy supply and to look at two viable alternatives to conventional oil consumption patterns.

It also represents a unique opportunity for Yukoners to learn from our neighbours. We have common experiences to share and, no doubt, we each have our own novel experience to compare.

I would like to tell you a little bit about Yukon so that you may understand us a little better. Yukon is a large region, some 200,000 square miles of forest, mountains, lakes, tundra and river valleys. But it is a land so sparsely populated that were you to give every man woman and child in Yukon 4000 acres you would still have left over an area greater than the size of England or Newfoundland.

All but one of our 22 communities are linked by a well maintained year round highway system. But the distances are significant and the costs involved in moving goods in and out are substantial.

Given these demographic and geographic facts you will begin to see the problems we face in Yukon. Add to that an economic reliance upon mineral extraaction and you have a picture of a land rich in resources but subject to the peaks and valleys of a fluctuating world economy.

Throughout the boom and bust cycles one thing is constant, our dependency upon oil. Yukoners spend up to $90 million each year on imported refined petroleum products. That works out to about $3,000 for every Yukon resident. Most, in fact nearly all, of that $90 million leaves the territory.

This is the situation Yukon faces today. If it seems to you that we are a small group of people in a vulnerable position you are correct. But do not believe we are helpless.

Yukoners have settled this country and called it home. The problems we face relating to geography and economy are not new to us, but they are problems which continue to present challenges for us.

The object of this symposium is to challenge head-on one of those problems, the dependence on oil. By ourselves we may never be fully independent of oil but we can reduce our dependence. Although there is little we can do to tackle the problem of transportation fuels, which eat up 50% of our oil bill, we are taking steps to reduce the 35% of that oil bill which goes for space heating of Yukon's residence and commercial buildings.

In Yukon today most of the houses we will need for the forseeable future have been built. This means that our architects, our builders, our tradespeople and their suppliers are going to be hard pressed to find work in the housing sector.

And yet look at the quality of that housing stock. Much of it was built before the dramatic rise in oil prices in the 1970's. Almost all of the housing in Yukon can be improved with the knowledge and the building practices available to us today.

Herein lies the opportunity for our trades and professional people to offer homeowners the expertise to upgrade their homes. If we are not building new homes then let us invest in our present homes. The retrofit of residences will not only pay for itself in energy savings and increased value but also will offer more comfort inside the home and more intergrity and longer life to the structures.

And it will keep an industry at work. In the north we face a common dilemma: a lack of diversification in our economy. We cannot afford to have the building industry underemployed. By keeping them employed in upgrading the housing stock we not only benefit from the work and the spinoffs from that activity, but we also benefit from the lowered demand for heating fuel which will result.

I have singled out the housing sector, but the same can be said for the industrial and commercial sectors. All buildings have space heat demands and I would venture to guess that there is not a building in the north whose thermal efficiency could not be improved in some way. The vast majority of them can be improved significantly and the work can be justified economically.

We have faith in that statement. We are currently involved in the retrofitting of 80 homes and apartments of senior citizens. We, in co-operation with the federal government, have invested nearly a half a million dollars in this pilot project this year and our estimates suggest that we will begin to see a return on our investment this winter. We expect to see a $150 thousand saving each year as a direct result of this work. We have increased the market value of these buildings, prolonged their lives, and provided a half million dollar stimulus to the building industry. Not to be ignored in this are the benefits which will be felt by the seniors themselves. Their homes will be more comfortable, and their fuel expenditures, on average, considerably less.

All of this sounds straightforward enough in this demonstration project, but if this concept of improving the energy efficiency of our current buildings is to be accepted widely by the public it will require some careful planning. If the investments in houses and other buildings are to be sound ones, then there will have to be noticeable skill development on the part of the builders, and improved levels of consumer awareness. In short, higher standards all round.

Just as no one today would consider constructing a building to turn-of-the-century, standards so no one in 1990 would consider building by 1970 standards. There is much to learn on everyone's part before we can begin to implement these ideas.

The Government of Yukon has already begun. We have offered four courses in the past year to carpenters, contractors, builders and interested private citizens on retrofit and energy-efficient new home design. This weekend we are one of the sponsors of Yes-fest, an annual event which attempts to raise the awareness of consumers in such areas as energy-efficient buildings and wood heat.

We feel one of the roles of government is to provide a forum where the exchange of information can occur among Yukoners and between Yukoners and our northern neighbours.

There is a common belief that by putting an airtight stove in one's house one is adopting a form of energy conservation. It is a belief which raises a number of points, and at the same time links the conservation of energy to the use of wood as a fuel.

Obviously, of a person switches from oil to wood heat but does nothing to upgrade the thermal retention properties of the building, no energy will be saved. In fact, since most wood heaters are less efficient than most oil heaters more energy will be wasted.

On the other hand, the consumer will be using a renewable resource and will be paying less for it. In addition, the money that consumer will be spending on the fuel will remain in the local economy. These two points cannot be ignored.

Nevertheless we have a trade-off involved in the conversion from oil to wood: less efficient use of a local resource versus more efficient use of an imported resource. The point I would like to make is that the trade-off is not necessary. Indeed, I am convinced we cannot afford it.

Whether you drove or flew to Whitehorse, in travelling here you no doubt became aware that we have a huge forest resource which covers most of our land.

But we have seen in other parts of this country, in other parts of the world what can happen to the land when the forest is used without proper long-term management. The forest is a renewable resource and represents a potential source for a tremendous amount of energy, but only if it is managed properly.

It has been calculated that 35% of Yukon's total energy needs, that is all of our residential and commercial space heating requirements, can be met by utilizing one half of the timber lost to annual fire kill in Yukon.

That is a staggering figure, but it is also somewhat misleading, because much of that fire killed timber is inaccessible.

Some of our communities, Pelly Crossing, Faro and Watson Lake, are situated near large burn areas. For these communities the potential energy is in ready supply.

But let me ask you: is it prudent that we strip the hillsides of their fire-killed timber and do nothing else: what will happen 10, 20 or 50 years from now? Will we still have enough wood in the immediate vicinity to meet the needs of these communities? In other words, are we turning a renewable resource into a temporary supply? And what of the communities like Whitehorse? In Whitehorse, a small town by North American standards, we have about 70% of Yukon's population. We are already threatening the forest resource within easy access of the city and we have no mechanism to replace it.

The responsibility for forest resource management lies presently with the federal government. I do know that this department is doing everything they possibly can to manage this resource but they have limited financial resources as well as expertise. A a government we are prepared to work with them in developing and implementing programs which will help us meet future needs.

We have to find ways of burning the wood more efficiently. Perhaps this will mean looking towards wood chips which utilize more of the tree and burn cleaner than round wood.

We have to find ways of harvesting the wood without destroying the land.

We have to find ways of ensuring a constant supply of wood close to our communities. Perhaps this will mean looking to energy plantations and developing fast growing hybrid trees.

We have to find ways of obtaining the funds necessary to do the research, to develop the infrastructure, and to do the planning necessary to ensure that this northern resource benefits the people and the economy of the north. What is really at stake here is the development of a new industry.

We have calculated that by supplying 35% of our energy needs in Yukon we would create over 200 jobs: jobs for researchers, harvesters, truck drivers, full-time jobs and seasonal jobs. That in itself is significant and when you consider the spin-offs in the local economy from the employment and from the money that will no longer be leaving to pay for oil bills, you can begin to appreciate the impact this can have.

We have to find ways also of developing the forest resources without creating conflicts with agriculture, wildlife, recreational activities and without irrevocably altering the wilderness.

But these are problems which can be solved. The technology to burn the wood efficiently exists or is being developed. The comprehensive forest biomass inventories are being gathered, the expertise to develop forest management programs exist.

If we are lacking in one thing it is that much of our knowledge is southern oriented. There is a crying need for northern based research facilities to examine these northern issues. This, at least in Canada, is a problem which must be addressed before too long.

In the next two days there will be 24 papers delivered on conservation and biomass topics. The topics are varied and I am sure the papers will teach us all many things. We have much to learn and this is a beginning. I have outlined some of the benefits which can accrue to us from our activities in these areas. They can have far-reaching effects on our economies, on our standards of living and on our personal comfort.

They can also have far-reaching effects on the philosophical approach to our lives. The challenge before us is to harness the resources of this land for the benefit of our people while maintaining a healthy environment. The challenge is to make a beginning, to take the first step in this direction.

PREFACE TO
34th ALASKA SCIENCE CONFERENCE -
ENERGY CONSERVATION SYMPOSIUM

When planning for this year's Energy Conservation Symposium commenced the initial intent was to orientate the formal presentations around recognized problems, particularly with residental housing, that were being encountered in Yukon. These problem areas included marketing, building standards, performance of log buildings, retrofit options and the indoor environment. As the program began to take shape two important things happened to alter the original plan. Firstly, it became unrealistic to find and obtain a committment from researchers to speak on the indoor environment question to the required depth. And secondly, there were architects, engineers and energy advisors who wanted to present their experiences of energy conservation implementation on a community wide basis. Thus, inevitably the search for indoor environment specialists was stopped and replaced by community oriented energy conservation programs.

A word is required here regarding the topic, 'Indoor Environment'. The intention for this topic was air quality and wide spectrum lighting. As air loss becomes less through retrofitting and new construction techniques, it is important to be aware of the potential for deterioration of air quality and steps must be made to deal with the problem. The need for the use of wide spectrum lighting, in the long dark winters of the north, is not so obvious because the adverse symptoms can be explained-away through other impinging factors. For example, when a headache occurs it is rationalized to be the result of insufficient fresh air or poor diet, wherein, one of the most important factors is, no doubt, living under lighting of narrow spectal range, when compared to sunlight. Both of these issues must be investigated in future conferences in order to round out the housing needs question of northerners.

As with most other scientific and engineering practices, the north has historically been a recipient of southern building codes and standards.

These housing types are hopelessly out of touch with the realities of the north,when heating mechanisms and codes are considered. Relatively cheap petroleum based energy sources, no doubt, were the willing culprits for this situation. The massive implementation of these technologies grew with little or no planning and certainly not with any thought regarding the eventual costs such casualness might cause. Well,it seems we have now come full circle. Historically as the indignous peoples of the north lived in harmony with their environment, so too we are trying to achieve the same.

New housing designs and standards are beginning to respond to the essential climatic factors, but alas not fast enough. Most importantly community energy planning and energy efficient retrofitting programs are only hesitantly being implemented. The marketing of real energy conservation options is almost non-existent in formal format. Are the reasons for this enmeshed in poorly defined priorities? There should be no effort directed against energy conservation due to falling oil prices. The world is going to need, and be thankful for, every barrel of oil saved through conservation today that can be used for plastics, or such, tomorrow.

The energy conservation symposium was formated to encourage and enhance technology transfer. Speakers were invited from Atlantic Canada, across Northern Canada, Fairbanks and Barrow, Alaska as well as Ames, Iowa to present their research of relevant technology and implementation strategies suitable for the north. Each session was arranged to enhance maximum information exchange through formal presentations and open floor question periods. All of the formal symposium presentations have been assembled in the following pages and are hereby published as the proceedings.

In parting I wish to acknowledge the following organizations and individuals for their assistance in helping to make the energy conservation symposium an unqualified success. Without funding the symposium would not have been and therefore I personally wish to thank the Energy Division, Department of Indian and Northern Affairs, Canada for sponsoring the Energy Conservation Symposium. The Energy Branch, Government of Yukon was extremely helpful in co-ordinating the symposium with the overall conference, and in particular, Patricia Fraser, Director, and David Arseneault, Publicity Officer, Energy Branch, Government of Yukon deserve enormous credit for the success of the symposium. I was Yukon Manager for Reid Crowther and Partners during the early stages of the symposium planning and I wish to thank them for their understanding and help in getting the program off to a good start. I would like to thank all of the program co-ordinators for the other symposia and the secretarial help I received from Cynthia Watson, Carol Laury and Elaine Shacker. The most important acknowledgements go to the symposium speakers and participating audiences. Without your essential participation all would have been for naught. I thank you all for an encouraging and exciting conference.

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Graeme Bethell

BETHELL MANAGEMENT
Victoria, B. C.
Canada

THE NEED FOR INNOVATIVE COMMUNITY FINANCIAL STRATEGIES THAT OFFSET THE FAILURE OF PRICE TO OPTIMIZE CONSERVATION INVESTMENTS

BY

Skip Laitner
Research Director
Community Action Research Group
P. O. Box 1232
Ames, Iowa 50010

ABSTRACT

Despite the mounting evidence of the benefits of conservation and renewable energy technologies, financial investments continue to be directed toward conventional energy supplies. A major reason for this situation is that energy prices, based upon inappropriate theory, are inherently biased in favor of using fossil and nuclear fuels. More importantly, price comparisons offer only a single dimensional look at the full economic impacts that result from an expenditure for a given energy technology. For these reasons, other economic measures should be explored in determining optimal energy investments in the future. One such measure is the multiplier effect which refers to the fact that when money is spent for a specific good or service within a community, a demand for labor and materials is created which, in turn, ripples through the economy and multiplies the value of the original expenditure.

Evidence suggests that even when the price for conservation and renewable energy technologies are higher than for conventional fuels, investments in the former tend to produce a larger economic return to the community. With this type of additional economic information, businesses and public policy makers can devise financial arrangements that enable a community to take advantage of a conservation investment even when their life-cycle costs point to higher prices.

1. INTRODUCTION

When Sir William Petty (1623-87), the true founder of modern economics, wrote his treatise on Political Arithmetic in 1671, economic theory took a major step toward establishing itself as an "objective" science in which functional relations between economic variables were identified and used to interpret the behavior of individuals in the marketplace. As Petty stated in his treatise, his aim was to explain his ideas of finance and trade through the use of numbers, weights, measures and statistics.

With the advent of Newtonian physics, also in the Seventeenth Century, the theorists of commerce and trade finally had a model of science that they could put to work for their own purposes -- a clockwork universe that had a highly predictable motion and gravitation. As if supported by the same Newtonian laws that brought order to the visible world, the market was viewed as a finely balanced system which would breakdown if tampered with beyond the scope of natural economic laws. The economic paradigm which emerged from this model was one that rested on the interaction between supply and demand and, in turn, worked with a price mechanism to ensure an optimal allocation of scarce resources. (Routh, 1975)

Unlike the world of physics, however, which by 1905-1926 began a major shift in its recognized paradigm -- for instance, the new paradigm, quantum mechanics, now accepted randomness rather than determinism in the universe, and it recognized that reality is "observer-created" and could be influenced by human intentions (Pagels, 1982) -- economics continued to adhere as it does today to its mechanistic roots that are more than 300 years old. Thus, we have the irony of an economic model which borrowed heavily from the world of science to build an image of objectivity but which failed to track the dramatic changes that have occurred in physics since Einstein first evolved his theory of relativity in 1905. Since the appearance of Political Arithmetic in 1671, it is economists rather than new ideas that have flowed.

Nowhere can this be seen better than in the failure of market pricing strategies to optimize the use of energy conservation and renewable resource applications. Despite mounting evidence to the contrary, investments continue to be directed toward the conventional fossil and nuclear technologies. (Laitner, 1981) One reason for this is that energy prices are derived from value judgments designed more to maximize the well-being of the business firm rather than of the community. One result of this is that prices cannot convey the information necessary for the consumer to make a rational choice among the competing alternatives in the energy sector.

2. NEW PARADIGMS IN PRICE THEORY

2.1 Failure in the Electric Utility Industry: An Example

The present financial condition of many electric utilities in the United States offers a clear illustration of a failure to re-establish an equilibrium between supply and demand through the pricing mechanism.

As a result of poor load forecasting techniques in the 1960s and 1970s (e.g., only recently has the term "price elasticity" been understood in the context of load forecasting), coupled with other questionable corporate policies, there presently is a large excess of electrical generating capacity in the U.S. One of the questions now before the beleaguered regulatory commissions is who should bear the costs of the unneeded capacity, customers or stockholders?

Passing these costs on to the customers through higher prices inevitably reduces consumption by some amount. This means fewer kilowatt-hours will be sold, fewer kilowatt-hours from which a company can recover its capital costs. Eventually the utility is forced to return to the regulatory arena to ask for additional rate relief that will offset the lost revenues. This brings still higher prices, another drop in consumption and yet another trip to the commission for help. Amory Lovins insightfully calls this the "spiral of impossibility." (Carrigan, 1982)

Part of the reason for this financially-crippling price spiral is the industry's insistence on keeping outdated rate designs that cannot track effectively the real cost increases inherent in the utility sector. (Laitner, 1983) But a larger issue is whether prices, even if set according to more appropriate criteria, can provide customers with the information and the incentives to optimize their choice. The answer is no, for two reasons.

First, prices are based largely on accounting costs and value judgments and are designed to maximize the gain of the utility, not to convey relevant information to the end user or the community about the impact of consuming electricity. For example, for each one million dollar expenditure on electricity, only one-third to one-half as many jobs are created compared to a similar expenditure on conservation technologies. (Laitner, 1982) But this information is missing from the price paid dor each kilowatt-hour consumed. Since the lost jobs are paid for in the form of higher taxes to maintain the various unemployment programs, there is no cause and effect relationship established in the minds of the consumer to suggest that his or her decision to use another kilowatt-hour of electricity likely will result in another increase in the unemployment rate, however small.

Second, even with this information made available in the form of an appropriate price adjustment, consumers may lack the capital to take advantage of another option that might simultaneously increase employment opportunities while maintaining the comfort level in the home. An audit of their homes may reveal numerous steps that could be taken to reduce consumption, but if there is no access to the up-front money necessary to pay for those conservation measures, use of electricity will continue even if shown to be a poor choice.

2.2 Shortcomings in Price Theory

Only by recognizing the shortcomings of pricing strategies as an allocation mechanism can we then take the necessary steps to optimize the use of our energy resources. Thus, we must evaluate price as a tool of the marketplace.

Starting at a very fundamental level, in order for us to know the price of a kilowatt-hour of electricity we first must know the value of the resources *in situ* used to generate the energy. Before this can be done, everyone must have an opportunity to bid on the use of those resources. This includes not only people in the present generation but those in future generations as well. Moreover, the bidding must be done on the basis of an equal distribution of income to fully determine the value of a specific resource. Under present arrangements this is an impossibility. Therefore we find in the very first step of identifying the value of resources the results are skewed suggesting that price cannot be an effective allocating mechanism. (Georgescu-Roegen, 1976)

Neither can prices account for pollution impacts even if some adjustment is made initially to incorporate information about this specific externality. For instance, suppose that $.10 per kilowatt-hour is the agreed-upon price which is necessary to maintain electrical consumption at a level so that a power plant emits no more than 15 tons of sulfur-dioxide per year. Over time the annual emissions will produce a cumulative, exponential impact upon the environment. (Gordon, 1979) To reflect that impact properly in the electrical rates, that portion of the price allocated to environmental costs must also rise exponentially. This is seldom done, if ever, since the market is too static to account for such changes. Moreover, since the higher prices will lead to some reduction in consumption, the utilities will pass on any changes in price only reluctantly if at all.

A third shortcoming of price is that by internalizing the costs of scarcity, thereby enhancing the value of a commodity, the loss of a resource actually may be accelerated since its value may prompt more people to mine it much as they would gold or other precious metals. In such instances prices may underpin economic growth, but it will be done at the expense of increased resource exhaustion. (Georgescu-Roegen,1976) This last point leads us to consider this related thought: what is the nature of the value reflected in a given price? Does the fact that a hospital bed is priced at $200 per day imply a measure of wealth (since it is included in estimates of the Gross National Product), or of our inability to promote better health?

TABLE I

ESTIMATED LONG TERM NET ECONOMIC EFFECTS OF A $1 PURCHASE OF VARIOUS ENERGY SOURCES

Source	Economic Multiplier	Money Exported From a State[a]	Net Economic Impact
Petroleum Products	1.35	.80	.55
Natural Gas	1.40	.81	.59
Electricity	2.02	.75	1.27
Home Conservation	2.55	.34	2.21
Solar	2.43	.31	2.12
Wind	2.54	.16	2.38
Biomass (gas)	2.36	.12	2.24
Biomass (liquids)	2.28	.12	2.16
Biomass (electricity)	2.25	.14	2.11

NOTE:

[a] Totals in this column relfect a dollar outflow for states like Iowa or Minnesota which have little conventional energy resources such as coal or oil.

Admittedly this round of criticisms is outside the normal operating assumptions involving price theory. But when such anomalies or inconsistencies arise, do we simply bend the facts to fit the paradigm, or should we begin the search for a new paradigm? One critic of price and general equilibrium theory stated: "a marvelous castle . . . but of no help in solving the housing problem." (Ricci, 1924)

2.3 Price Versus Its Multiplier Effect

Microeconomic theory has oriented pricing techniques in such a way as to maximize the well-being of the firm. The interests of the community, according to theory, are served when firms compete for business from the community members. By comparing prices consumers are given a chance to optimize their own welfare since a rational person will choose a product that will suit his or her needs at the lowest possible price. But as we previously noted prices offer only a single dimensional look at the full economic impacts that result from expenditures made for energy, even diregarding the so-called "external" costs such as pollution.

To more fully account for the economic consequences of a specific purchase, I suggest we look not to the price but to the multiplier effect generated by the purchase. This refers to the fact that when money is spent on any good or service, a demand for employment and manufactured products is created that, in turn, ripples through the economy and multiplies the value of the original expenditure.

Perhaps the best way to look at this is to envision the purchase of a new home. When you sign a purchase contract you are paying for the wages of those people who built the home. They now have the needed income to pay for the rent or mortgage on their own homes. Thus the value of the purchase is increased. Moreover, the contractor has to purchase the lumber to build the house and perhaps to replace any worn out equipment that might cause inferior work. These secondary purchases also require labor and materials. After adding these total effects and then accounting for any "leakages" or outflow of dollars from the region, we then have an estimate of the net increase in economic activity or output generated for each dollar of original demand. Different purchases will have different multipliers which have no relationship to prices, at least not directly. Table 1 compares the net multipliers for a number of different energy conversion technologies that are typical for Iowa. (Laitner, 1981)

If prices do, in fact, tend to optimize resource allocation, then some correlation should be discerned when comparing a price for an energy purchase and its resulting multiplier effect. But as Table 2 shows, no real correlation exists. Among the conventional energy sources, natural gas has the best value for the consumer with a price of $4-6 per million Btus. But its purchase returns only $.59 on the dollar to the Iowa economy. Electricity, clearly the most expensive conventional resource, has a higher overall return to the economy when compared to either fuel

TABLE 2

COMPARISON OF TYPICAL ENERGY PRICES WITH THEIR RESULTING MULTIPLIER EFFECTS

Source	Current Prices	Net Multiplier
Conservation	\$2-10/mmBtu	2.21
Passive Solar	\$6-12/mmBtu	2.12
Biogas	\$4-18/mmBtu	2.24
Electricity	\$15-21/mmBtu	1.27
Natural Gas	\$4-6/mmBtu	0.59
Fuel Oil	\$7-9/mmBtu	0.55

NOTE: one million Btus is approximately equal to 293 kilowatt-hours of electricity, 7.2 gallons of fuel oil, and 1000 cubic feet of natural gas.

oil or natural gas. On the other hand, conservation and the renewable energy technologies generate a larger net return even though in some cases they might cost more than the fossil fuels.

To illustrate how the introduction of the multiplier effect can alter an apparent value of a product, let's compare the economic benefit that might result from the continued purchase of natural gas to home conservation measures.

If we assume that the average price of natural gas is expected to be $6.00 per million Btu (mmBtu) while the life-cycle cost of the home conservation measures is projected to be as high as $8.00/mmBtu, from both the utility and the homeowner's perspective the continued purchase of natural gas appears to be the preferred option. Introduction of the multiplier effect yields a different result, however, as the following calculations indicate:

$$1.0\ \text{mmBtu}_{gas} \times \$6.00/\text{mmBtu} \times .59 = \$3.54 \quad (1)$$

$$1.0\ \text{mmBtu}_{con} \times \$8.00/\text{mmBtu} \times 2.21 = \$17.68 \quad (2)$$

As equations (1) and (2) suggest, despite the higher costs associated with conservation, an expenditure there generates five times (17.68/3.54) the economic activity as an expenditure for natural gas.

The second equation must be adjusted to account for the fact that the two extra dollars spent for each million Btus conserved can no longer be spent for other commodities, each of which have their own multiplier. If we further assume that the average consumer expenditure generates a return of 2.5 times, then equation (2) must be modified to reflect the loss in economic activity made by diverting normal consumer expenditures into home conservation costs:

$$\$8.00/\text{mmBtu} \times 2.21 - (2.50 - 2.21 \times \$2.00/\text{mmBtu}) = \$17.10 \quad (3)$$

Thus, even with this downward adjustment in this example, conservation continues to provide the greater benefit to the community. This is something that cannot be revealed by comparing the prices of different energy strategies.

3. THE TRAGEDY OF THE COMMONS REVISITED

In his seminal essay, "The Tragedy of the Commons," Garrett Hardin wrote that a rational person finds the cost of discharging sewage into local waterways, since it is a cost that is shared by the whole community, will be less than the costs of purifying the sewage, a cost that is borne by the individual alone. "Since this is true for everyone, we are locked into a system of 'fouling our own nest,' so long as we behave only as independent, rational, free-enterprisers." (Hardin, 1968)

A similar parallel can be drawn with the consumption of energy resources. Following Hardin's analysis, if a homeowner in a community of 25,000 people chooses to continue the purchase of natural gas rather than go with appropriate conservation measures, there is both a negative and a positive utility to that decision. The positive component is the savings of $2.00/mmBtu. The negative component is the loss to the community of $13.56 in economic activity for each million Btu saved, essentially the difference between equations (1) and (3).

Since the loss of economic opportunity is shared by the entire community, the negative utility of $13.56, divided by the town's population, is only $.0054 for the homeowner. Even if he or she is aware of this disutility at all, the rational person, based on the price mechanism, concludes that the only sensible course of action is to continue with or to increase natural gas consumption. Paraphrasing Hardin: "But this is a conclusion reached by each and every rational homeowner in the community. There is the tragedy. Each of us is locked into a system that compels him or her to maintain or increase consumption without limit -- in a world that is limited." And as he concludes,"the great challenge facing us now is to invent the corrective feedbacks that are needed. . ." In this case our task is to look for a corrective feedback to the existing pricing system as it applies to energy use. As Keynes noted: "The difficulty lies not in the new ideas, but in escaping from old ones, which ramify, for those brought up as most of us have been, into every corner of our minds." (Keynes, 1935)

4. STRATEGIES TO COUNTER THE PRICE MECHANISM

Although the idea of the multiplier effect may be understood in concept, a community might wonder how the information can be applied to create an opportunity for using conservation as an economic development program, especially when conservation applications appear more costly than continued use of natural gas.

One approach might be for a local city council to look at ways to "buy down" the cost of conservation for residents and businesses. In effect the local government can use its own ability to generate revenues to invest in local residents so that costs of conservation materials and services are made more competitive with natural gas. Rather than view such a strategy as a subsidy to a homeowner, adopting a new paradigm the council might think of it as a prudent investment in the community with the profit coming in the form of a net gain in economic output as measured by the multiplier effect.

To illustrate how a community can "profit" from using its financial position to underwrite conservation investments, let's assume that the local council funds a non-profit community development corporation. By taking advantage of its access to lower-cost capital and to large volume purchases unavailable to a single homeowner, the cost for conservation improvements might be brought down to $5.00/mmBtu saved. This price is not only competitive with natural gas purchases, but will actually produce a savings to the homeowner since he or she avoids some purchase of \$6.00/mmBtu gas.

The city council will want to know, however, what is its return on the investment of \$3.00/mmBtu saved. Accounting for the increase in economic activity generated by the conservation program, the loss in activity resulting from the diversion of tax dollars away from normal expenditures, and the loss of natural gas purchases, we have the following:

$$(8.00 \times 2.21) - (\$2.00 \times 2.50 - 2.21) - (\$6.00 \times .59) = \$13.56 \qquad (4)$$

(Note: since the price for conservation was "bought down" to \$5.00/mmBtu, the homeowner will now have an extra dollar to spend since he or she does not have to pay \$6.00/mmBtu for natural gas. Because we've set the multiplier for both average consumer purchases and for tax dollars at 2.5 for purposes of this illustration, the net effect is to reduce the economic loss of the so-called three dollar subsidy by one dollar multiplied by the 2.5 figure. Hence the middle term reads \$2.00 rather than \$3.00.)

Under a "business-as-usual" approach outlined in equation (1), the community realizes an economic gain of only \$3.54/mmBtu, less than what is originally spent to buy the natural gas. The three dollar investment per million Btu of conservation, on the other hand, yields a return or community profit of \$13.56. The conclusion that should be drawn from this analysis, then, is that local governments can use their own financial resources to counter the inability of energy prices to maximize the community's welfare. As long as the investment made by the community does not offset the gain in the net economic activity, then community financing strategies for local conservation efforts can play an important part in restoring a more optimal allocation of resources where prices alone fail in that task.

5. CONCLUSION

Introduction of the multiplier effect into community energy plans can provide local policymakers with an important decisionmaking tool that will help determine what level of local investment is appropriate to "buy down" the costs of more optimal energy technologies. However, more work will need to be done to establish accurate regional multipliers for the various energy technologies, and to determine how they will change as the prices of other goods and services change. Moreover, since multipliers are a function, at least in part, of prices which we've already determined may not reflect the value of resources as well as theory suggests, the local councils that employ them in their decisions should allow for some range in setting the level of investment activity. For example, although conservation has been shown to have a multiplier of 2.21 in this example, it may have a measure of error of ± 10%. The council could then decide to use the lower end of the range, approximately 2.0, as the basis for its calculations rather than the given multiplier itself. Despite these limitations, it is clear that if we wish to make full and efficient use of our diminishing resources, our decisions as to which ones are to be developed and how they are to be used must include criteria other than price alone.

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MARKETING ENERGY CONSERVATION

A STRATEGY FOR THE 80's

DENNIS N. EDELL
IEA CONSULTING GROUP LTD.
OTTAWA, ONTARIO

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MARKETING ENERGY CONSERVATION

DENNIS N. EDELL
IEA CONSULTING GROUP LTD.
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Marketing is the strategy behind the selling of a product or idea. The creation of an effective marketing strategy should attempt to find the right fit of a product or an idea with a receptive market supported by the right mix of pricing, promotion and distribution programs.

Effective residential energy conservation strategies attempt to optimize the use of energy in the home through the efficient application of energy saving practices, measures and technology.

By marrying effective marketing concepts to energy conservation programs we can begin to bridge the gap between what starts as a good idea and what becomes common practice. Our objective is to persuade as many people as we can to adopt effective and appropriate energy conservation technology in their homes and daily life.

In the past decade, through the necessity of steeply rising fuel costs and a questionable supply of fuel oil, we've learned a lot about what can be done in homes in the North in order to heat them affordably and make them more comfortable. However, if we can't persuade people to be aware of, and actually do the things we know they should do, then we're wasting our time developing new technology. Consider the old farmer who returned to his local hardware store with his new chainsaw and complained "The damn thing doesn't cut wood worth a hoot". The repairman was puzzled because he knew he sold that farmer a good saw, so he pulled on the starter cord and sure enough the chainsaw started right up; the farmer jumped and yelled "what the hell was that noise!"

A successful marketing strategy, whether it's for insulation companies, heating equipment manufacturers, public policy makers, or a community action group promoting energy conservation, must understand how the products or ideas which are being offered interact with consumers in the market place. I don't care how nice your brochures are you're just not going to sell gas furnaces in Whitehorse. Sounds silly but people are always pitching the wrong products to the wrong people.

In developing your marketing strategy for energy conservation it pays to take a closer look and define your product or idea in terms of its impact on the householder. First, in a generic sense, any practice or measure that saves or conserves energy falls within this category. However, in a real sense, householders tend to perceive energy conservation as a larger issue and will confuse energy savings with dollar savings. Energy savings will, in this sense, include demand shifts which replace one source of energy with another, potentially cheaper source of energy for example, active and passive solar systems, wood stoves, and furnace conversions. Thus, to the householder energy conservation conjures up almost any energy related product or gadget used in the home.

Secondly, a marketing strategy for energy conservation recognizes that there is, more or less, a definite process that people follow in deciding whether or not to adopt energy conservation, and that this process is different for low cost, low commitment practices, maintenance activities, and higher cost; higher risk measures.

Low cost practices are actions such as thermostat set-back, turning down the hot water heater temperature, or washing clothes in cold water. These practices involve little cost and are easily implemented. To everyone in this room it probably makes eminent sense to lower your thermostat to 65°, but I would bet that less than half of the people here, and certainly far fewer in the general population, carry out this and other simple, proven practices, why not? Because lowering your thermostat, and wearing a sweater around the house involve lifestyle changes that many of us are simply not willing to make. Social status and the associated values that people attach to certain actions are strong motivators. Many people will not keep their homes cooler even when shown the value of the action because they feel that this action represents a lower standard of living.

Maintenance behavior such as weatherstripping, caulking, and furnace tuning, requires time, effort and attention on a regular basis as well as an outlay of funds. Householders are somewhat concerned about whether these products or measures will work but can usually be convinced to try simpler measures such as caulking or weatherstripping; or heating system maintenance without too much armtwisting. But, they will only try these once or on a limited basis until they are satisfied that there are real benefits resulting from their efforts. Is my heating bill lower? Do I feel fewer drafts around this window? Does the oil furnace kick-in fewer times each night compared to last year when it wasn't tuned? If householders actually receive or even perceive they are receiving positive benefits from their actions, they will, when you remind them, upgrade or replace caulking, check and install weatherstripping, have the furnace tuned or replace the air filter or carry out other energy saving activities on a regular basis. Success with small actions leads to confidence about venturing into the more costly conservation actions.

Investment decisions are the third category of energy conservation measures. As their name implies, they represent the higher cost, more substantial measures, for example, basement insulation, or a new heating system. The commitment of discretionary income, and householders' increased need for product information and specific cost/benefit statements, characterizes householder's approach to these more permanent investments. Not only must I be convinced that it will work in my home, but I want to know how much I will save. Is this really what I should be doing with my hard earned money? In fact, the more visible the product the more active the information seeking will be. Woodstoves and heat pumps can be the object of countless discussions and shopping comparisons. Insulation, although equally as dynamic in terms of energy saving, rarely gets the same attention. People are far more liable to go with the first insulation contractor that approaches them rather than shop around. Conversely, the further away the payback and the longer the continuum of savings, the more householders will be anxious about their commitment to future energy savings after the decision was made. Did I make the right decision? Did I hire the right person to do the job?

Funds available for financing these measures will, to a large extent, determine what is done. Irregardless of the promised rate of return, householders have resisted borrowing for energy conservation improvements. We should also recognize that investments in energy conservation measures compete with other uses of discretionary income. Insulation does not compete with more insulation for family funds but is more likely to compete with a trip to Florida, a new snowmobile, or a sauna. To give you some idea of the complexity of the situation, here is the result of one consumer survey which attempts to identify factors that explain overall spending on insulation.

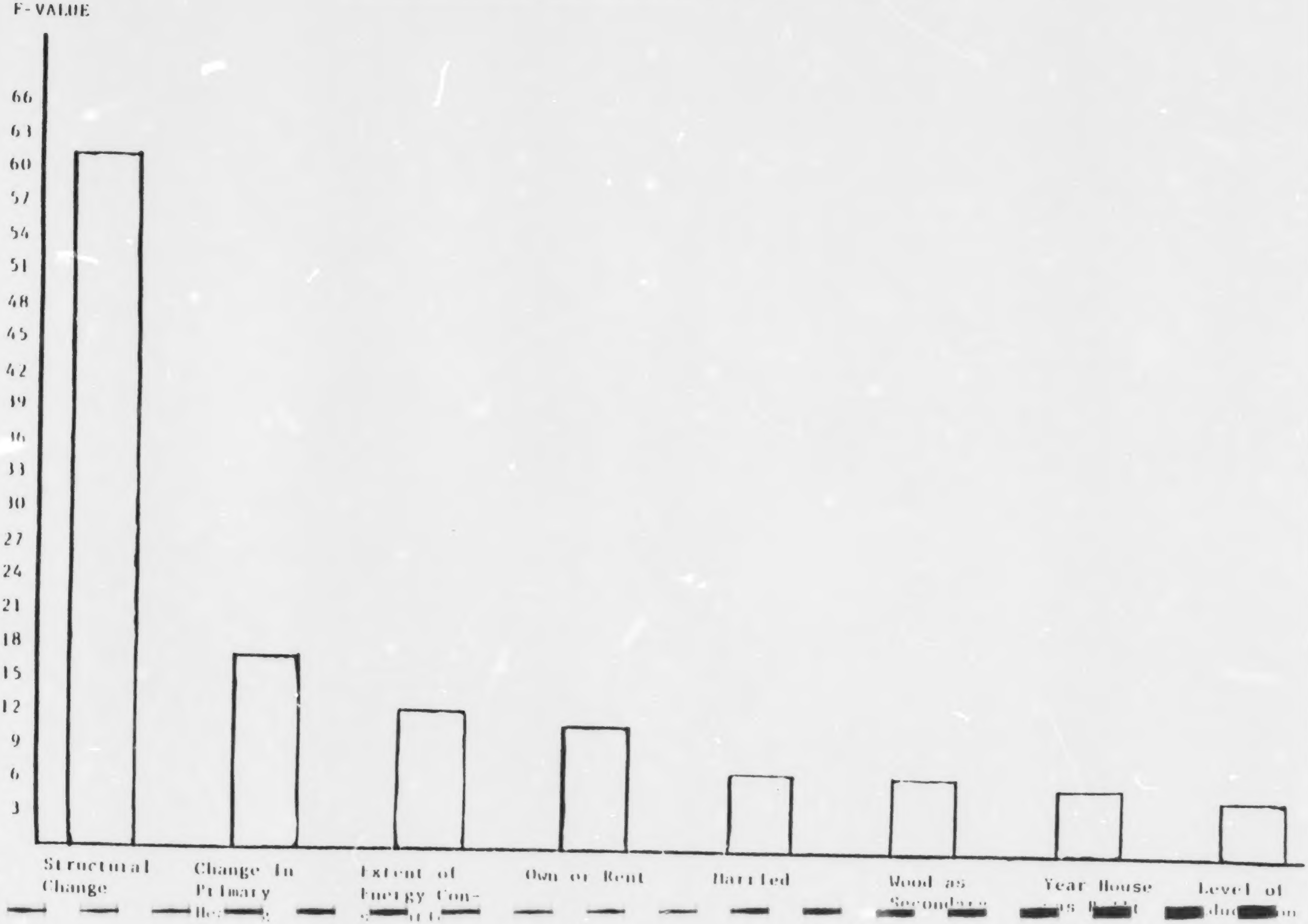
This may seem a rather simplistic look at a complex problem but it provides some insights into householders' decision-making process concerning energy conservation improvements. Let's look now, at the environment in which these decisions are made.

Although in 1983 the price of energy in the north and throughout Canada has never been higher, our sense of urgency is gone. Oil prices have, for the time being, stabilized and the supply problem is generally felt to have peaked. "Whatever happened to the future?" The environment has flip-flopped on us in terms of a crisis atmosphere, yet the real need for energy conservation has never been greater. As we said, the price of energy has never been higher yet the economy as it exists outside of the Windsor-Montreal corridor is still struggling to free itself of the worst recession in more than fourty years. Unemployment levels are still high and inflation is just starting to approach bearable levels.

Just as an understanding of product dimensions can bring some insights into our marketing strategy so is it necessary to understand how consumers, your audience are reacting to today's environment of inflation, recession, and high energy costs. In this sense I have some bad news and some good news. The bad news is that no one is any better off during tough times. The good news is that people in the south have shown the same strength and resiliency which has always characterized their cousins to the north. At the close of 1982, the Canadian consumer looked like this:

- Inflation means that income must be raised just to stay even. In more families both partners are working and the underground economy has flourished. Garage sales, backyard gardens, taking in boarders, and bartering with neighbors for services are now relatively common strategies.
- Consumption patterns have changed - People are not cutting back across the board but spending their money more selectively. Quality has become a very important word in these times. Consumers have indicated that they will be willing to spend more if it means additional value for money. When times are tough people feel they cannot afford to waste their money on products or services which do not perform.
- Self-sufficiency is a growing trend amongst Canadian consumers. Canadians are generally doing more things for themselves. The do-it-yourself movement has enjoyed a resurgence. Consumers who were used to paying for repairs are now acquiring tools and supplies and taking how "to" courses at community colleges in order to tackle these jobs themselves.

KEY VARIABLES EXPLAINING OVERALL SPENDING ON INSULATION



- Community reliance is also on the upswing. Sharing, trading and cooperation amongst neighbors is more and more evident across the country.

- Bargain hunting has increased as a means of saving. The past few years has seen the emergence of no-frills shopping and the shopper who will spend more time visiting different stores in search of a bargain. Consumers are less loyal to brands or stores when it comes to saving money and are willing to forestall purchases and wait for a sale.

- Canadians seem to be simplifying their lifestyles by necessity and not by choice. Those, who by their own choice, abandoned the high consumption consumer lifestyle of the early 70's for a bulk food lifestyle were termed voluntary simplifiers. Now, however, consumers who are cutting back, simplifying, and doing without, are doing so involuntarily and have expressed negative feelings. They consider themselves as being deprived of a more comfortable lifestyle and intend to return to old patterns when things get better.

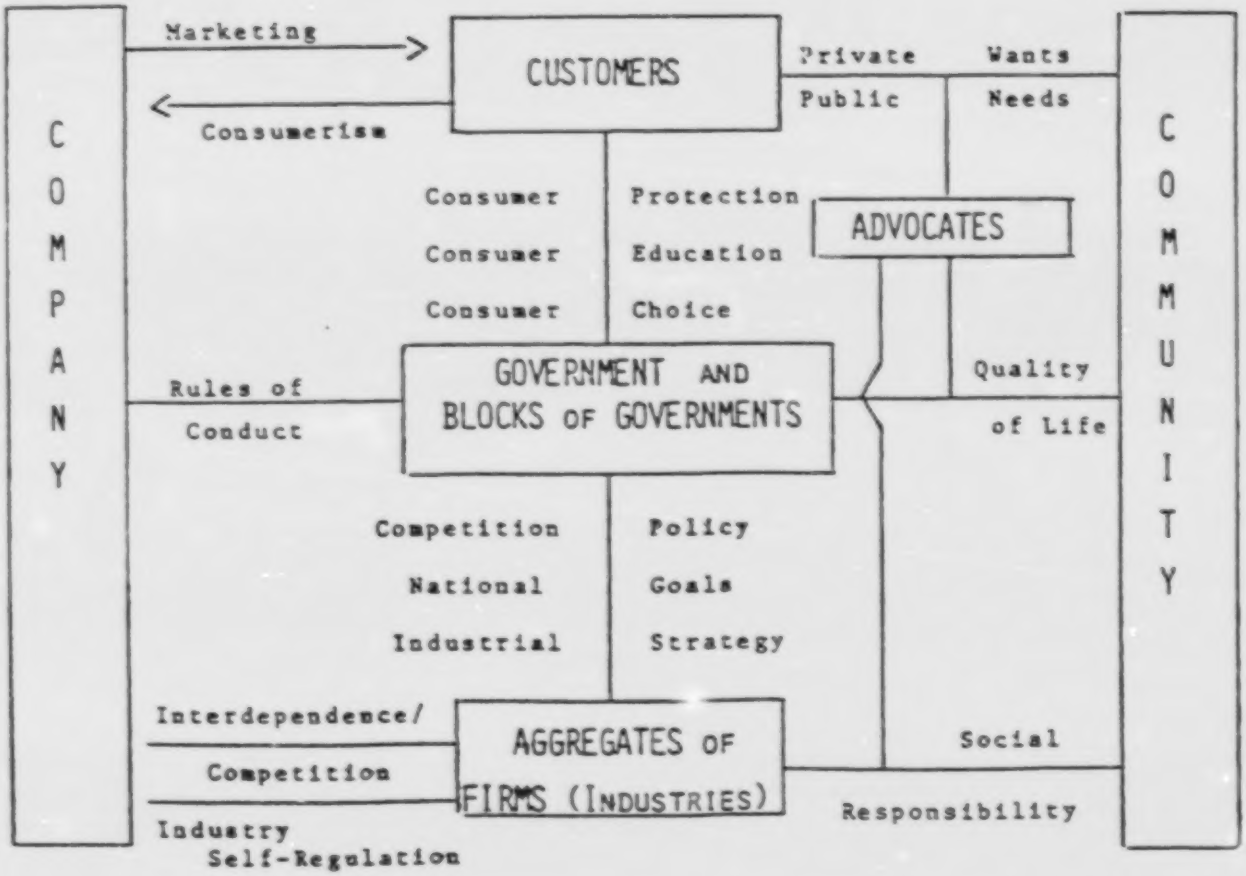
- Because of present uncertainties, people are confused and fearful of credit purchases. Major purchases are being avoided until the present economic difficulties show a clear sign of having turned the corner.

Out of these trends I think we can begin to form a picture of a cautious and wary consumer. One who will spend money, but will be interested in receiving real value for his or her money. Certainly a less frills world works to the advantage of energy conservation. The intrinsic value of energy conservation measures promise a healthy return for a consumer beset by inflation deflated incomes and high heating costs.

The last area I think we should consider before formulating some actual strategy suggestions is an appreciation of the maze of power relationships which exist between government, consumers and industry. Each sector exerts pressure on the other in order to meet its self-serving objectives. Companies want to sell products and make profits, consumers desire a high quality of life, and governments need to get elected. These objectives frequently rub against each other in the market place and the players become locked in battles in which everyone loses. However, an understanding of these needs can avoid the pitfalls of overly adverse relations.

The creation of returnable bottle laws is a good example of how inattention to these relationships brings about reactions from all sides: container companies and beverage bottlers felt they had every right to sell their most profitable product. Their marketing research told them that consumers wanted the convenience of disposable containers. What they didn't realize was that behind the individual customer was a collective sense of community. This community didn't feel that broken glass and tin cans on the highway were necessarily good for the community. The community voiced its wants through the intervention of consumer advocates since the beverage industry didn't seem to indicate any willingness change. *Consumer advocates put pressure on governments* who passed laws banning non-returnables much to the consternation of the container industry who fought the legislation and wound up appearing to be a rather irresponsible corporate citizen.

A CONCEPTUAL FRAMEWORK FOR MARKETING AND PUBLIC POLICY ISSUES



COMPANY
Marketing
Consumerism
CUSTOMERS
Private
Public
Wants
Needs
COMMUNITY
Consumer Protection
Consumer Education
Consumer Choice
ADVOCATES
Rules of Conduct
GOVERNMENT AND BLOCKS OF GOVERNMENTS
Quality of Life
Competition Policy
National Goals
Industrial Strategy
Interdependence/
Competition
Industry Self-Regulation
AGGREGATES OF FIRMS (INDUSTRIES)
Social Responsibility

I don't want to put all the blame on industry. There are numerous examples of consumers, and governments acting without regard for the interests of other groups.

However, I have touched briefly on this subject so that we can be aware that it is not just supply and demand which moves the market and that when pressure is exerted on one sector another sector is influenced and will react accordingly.

Finally, I would like to leave you with some suggestions to keep in mind when you are formulating your marketing strategies for energy conservation programs.

You will get more bang for your buck if you recognize that:

1. Householders will act if they can be shown that it is in their economic self-interest to take energy conservation actions. Appeals to altruistic goals or values will most likely have a very minimal impact.

2. Today's consumers are active seekers and processors of information. They are giving more and more of their attention to the functional attributes of products rather than style or fashion. Present them with hard information in a clear format. Don't try to be overly cute or sexy.

3. While many people are cutting back and conserving energy they may not be doing it willingly. Don't try to play on what some people might consider a negative trend by encouraging people to wear sweaters in a cold home. Rather, tell them how a comfortable, energy efficient home, improves the quality of their lives.

4. Householders want to help themselves. They feel more secure in their independence. By encouraging and helping householders to install energy conservation measures themselves, you are responding to this need.

5. Consumer's reaction to the promotion of energy conservation can be an emotional issue. Culture, peer pressure, security, lifestyle, status, and personal goals define a family's set of values. At the centre of this set of values lies a very important entity, the home. Within each country, each region, and each family, the home conjures up a unique set of attitudes. The impact of your program will depend on the extent by which you can understand these values, focus your message to speak to the needs of the householder and adapt your product or idea, to satisfy these needs.

BUILDING STANDARDS FOR NORTHERN CANADA

BY
RICHARD BUSHEY
BOX 68
YELLOWKNIFE, N.W.T.

BUILDING STANDARDS FOR NORTHERN CANADA

Over the last year a residential standard has been developed to encourage the construction of energy efficient housing in those areas of Canada north of the southern limit of discontinuous permafrost. This standard has been ordered by the Treasury Board of the Government of Canada and is to be applied for the 1984 construction season for new residential construction.

The objectives of the standard are to promote energy efficient building designs, equipment and building practices that are suitable to northern lifestyles and the unique climatic conditions found in the various Northern areas.

The project is concerned with incorporating the experience of northern builders in Canada and from other countries in constructing stable foundations on discontinuous and continuous permafrost soils, airtight building envelopes, suitable heating and mechanical ventilation systems and implementing energy conservation technologies that have been developed in recent years.

In 1980 the Canadian National Energy Program introduced many conservation and renewable energy projects. Two projects directed at the residential building sector, are the R-2000 Super Energy Home and the Northern Residential Standard for Energy Efficient Housing Project. The principal goal of both efforts is to promote the design and construction of energy-efficient or air-tight homes.

What is an energy efficient home? How does it differ from conventional practice? And what are the advantages?

In an Energy Efficient home the objective is to reduce the space heating requirements of a conventional house built within the Residential Standards of the Canadian National Building Code by anywhere from 40% to 80%. This is accomplished by designing a building which has significant characteristics:

1) high levels of insulation that are appropriate for the climatic location of the home

2) the reduction of air leakage through the building envelope to insignificant amounts; and, in turn, to provide an adequate controlled supply of fresh air to the living area and for the combustion equipment used to heat the building

These basic principles as applied to residential housing are not new. The concept of the energy efficient or airtight home was developed as early as 1975 when the Swedish Building Council set standards for thermal insulation and a maximum rate for air change or air leakage in a residential home. In Sweden, the maximum air change rate for a single family home is 3.0 air changes per hour measured at 50 Pa pressure difference. And, it is in Sweden where many tests and innovations have been developed in the construction of joints and seals, external wall frameworks to accommodate thick cavities for insulation, wind and weather protection.

In Canada similar work has been conducted in developing high standards of air tightness and construction in order to reduce the annual heat loss of a building to very low levels. In the R-2000 Super Energy Homes the building requirements are straightforward:

1) the house must be constructed sufficiently tight in order to test at 1.5 (ach) at 50 Pa as proposed in the Canadian General Standard for determining airtightness by the fan depressurization method.

2) a minimum rate of.5 (ach) ventilation rate controlled by mechanical means is required for adequate air supply.

3) in addition a design formula is introduced that requires that the building be constructed to meet a total annual energy budget, for example 50 kwh of energy per square meter of

building area at a 6,000 D.D. location

The R-2000 homes, assisted by the Hot Can house design computer simulation program, is a performance requirement program specifically created to encourage the development of low energy construction techniques and materials within the Canadian building industry. Over 300 homes were under construction nationwide in 1983 including the N.W.T. and the Yukon.

The Northern Residential Standards for Energy Efficient Housing project is a comprehensive prescriptive and performance building guide directed at the North, specifically those areas in the continuous and discontinuous permafrost regions.

Like Alaska much of the building design and practice in Northern Canada has been inherited with some modification from southern Canada and the "lower 48". As a result energy consumption in residential housing is high. In a recent report analyzing the space heating and electricity consumption of approximately 1,000 pre-fabricated, panelized homes built in the Northwest Territories between 1973 and 1978, the average home consumed $4,000 to $5,000 (1981 dollars) worth of energy. Some housing units less than ten years old tested at 15 (ach) and were rated as very poor.

In the Northern Residential Standards which is nearing its first draft production stage, an attempt has been made to develop a document which combines the research developed in Sweden, Canadian experience in building Super Energy homes and the experience of Northern building professionals and residents. Since the Northern standard will be the basis for new construction in the Arctic and sub-Arctic regions great care has been taken to develop a technical Committee and a consultation process which can address the many unique climactic, geographical and transportation problems of the North and to arrive at an acceptable consensus for a building standard.

The Northern Residential Standard encompasses all aspects of building construction, fire and safety considerations and site development. However, I would like to concentrate on one of the most controversial areas of the proposed standard and one of the most integral aspects of Energy Efficient building design - the ventilation system.

Recent studies have shown that approximately 25% of the heat loss of the current housing stock in Canada can be attributed to air leakage. In the North, it is much higher.

Since Energy Efficient Homes are relatively airtight, uncontrollable air leakage is not significant. Subsequently controlled ventilation is necessary in order to provide combustion air for fuel burning appliances and to maintain adequate indoor air quality for inhabitants.

It is the designer of an airtight house who is responsible for creating an air management system that provides adequate make-up air and ventilation while retaining energy-efficiency. To achieve energy-efficiency, heat recovery is usually integrated into the air management system via a heat exchanger which extracts heat from the exhaust air in the ventilation system and passes the heat on to the incoming fresh air. The questions that remain unanswered are:

1. How effective is the heat exchanger in recovering waste heat in Northern regions?

2. And what is an appropriate level of ventilation and control for safety and adequate air quality?

Ventilation standards were developed in the 1930's in the U.S. through experimental work which recognized the importance of controlling indoor air quality and air quantity measured in cfm's/per person. The goal was to provide "odor-free" living environments as functions of available air space per person. The assumption was also made that outdoor air was pollution free. Known as the Yaglou studies this work became the principle reference for all subsequent codes and standards.

However, as we now know, many factors can influence air quality in a building:

Pollutants such as formaldehyde in construction materials and furnishings; cigarette smoking, cleaning solvents and the combustion devices of fireplaces, stoves and furnaces; numbers of people in a household can vary from time to time and this affects air quality significantly.

As a result ventilation requirements can be prescribed as

- volumetric flow rate per person
- volumetric flow rate per unit of floor area
- or room air exchange rate per hour

The attempt is to prescribe a requirement for indoor air quality which is safe and yet discourages heat loss. If sufficient ventilation rates are not prescribed to meet any foreseeable variability (such as a power outage) the resultant indoor air could be harmful or in short supply. Conversely, if sufficient ventilation rates are prescribed to meet all contingencies, energy efficiency is lost.

At present, the Northern Standard is requiring a minimum .5 air change per hour of the cubic volume of the interior heat space that is mechanically controlled. Heat recovery is not required because there is yet no Canadian Standard approved air to air heat exchanger.

In closing, I would like to illustrate the significance of heat recovery in mechanically controlling the ventilation in an airtight home measured in possible energy savings in the North.

Three NRC Hot Can computer design analysis of a single storey home built under the R-2000 program in Northern B.C. and the Yukon were analyzed. The home was located in the Great Slave Lake region of the Southern Mackenzie in the N.W.T.

Labelled CROS1 this airtight unit was analyzed at the R-2000 criteria: a natural infiltration rate of .05 ach; a mechanical ventilation rate of .45 ach. Without heat recovery in the ventilation system this house was estimated to consume 32,857 kwhrs of energy.

In CROS2, the same house with the same ventilation rate, but with heat recovery rated at 55% efficiency installed produced an energy budget estimated at 24,356 kwhrs of energy. An approximate 7,500 kwhr saving over CROS1.

In CROS3, again the same unit, the mechanical ventilation rate was reduced to .25 ach and heat recovery effective at 70% was introduced. As a result the energy budget estimate was reduced to 19,404 kwhrs, approximately 13,500 kwhrs less than CROS1.

It is apparent that we have the capability to build well sealed and insulated air-tight homes. In turn, we then require controls to ventilate homes for combustion equipment and for the inhabitants. The minimum requirements for safety and energy efficiency are still controversial. High efficiency combustion equipment and heat recovery devices have yet to be fully tested for Northern conditions. However through the monitoring and testing of R-2000 homes within the next year and the encouragement and support of energy product development, we hope that a satisfactory Northern Residential Energy Efficient Building standard can be produced for the 1984-85 building season.

R-2000 HOME TECHNICAL CRITERIA

The annual space heating requirement for all houses is to be determined by computer simulation as specified by EMR and HUDAC. The minimum standard of performance for all houses is to be derived from the following formula:

$$\text{ETOTAL} = 10{,}600\ \text{kWh} + \left[\left(\frac{5\ \text{kWh}}{\text{m}} + \frac{45\ \text{kWh/m}^2}{6000\ \text{C-days}} \times \text{D.D.}\right) \times \text{M}^2 \times \text{U.T.F.}\right]$$

where - E total = the buildings total annual energy target (kWh)

- D.D. = annual degree days for the location (c-days)
- The term in the ( ) brackets = the buildings per square meter skin loss target for space heating (kWh)
- M^2 = equivalent floor area in square meters (m^2) calculated as follows:
  1. the heated volume of the house in cubic meters based on the inside dimensions is calculated;
  2. the heated volume of the house in cubic meters is divided by 2.5 to arrive at the equivalent floor area in square meters (m^2).

- U.T.F. = Unit Type Factor, set at 1.0 if a single detached unit is being considered, 0.70 if double multiple units are being considered, 0.65 if triple multiple units are being considered, and 0.55 if quintuple or greater multiple units are being considered.

Buildings built under this program will be required to meet the following additional requirements:

1. Airtightness

   The house must be constructed sufficiently tight in order to test at 1.5 airchanges per hour (ach) or less at a pressure differential of 50 pa. as per the proposed Canadian General Standards Board standard for determining airtightness by the fan depressurization method. For calculations in the design stage, an infiltration/exfiltration rate of 0.05 airchanges per hour will be assumed.

2. Air Quality

   The house must have a minimum of 0.5 ach ventilation ability that is controlled by mechanical means to ensure adequate air quality. For purpose of calculation:

   a) ventilation is assumed to be continuous

b) heat recovery systems, if utilized, are considered to only modify the controlled ventilation rate.

3. Temperature Swings

The house must be constructed such that temperature swings within the building's liveable area are limited to 7 Celsius degrees above normal indoor temperature during the heating season. Normal indoor temperature being defined at 21°C for living space and 18° C for basement spaces.

4. Windows

The house must be constructed such that any double glazed windows installed, whether fixed or operating, have an airspace of a minimum of 12.5 mm between the panes.

5. Wall Construction

Exterior above grade walls must have a total component resistance factor of greater than R.S.I. 3.50.

6. Combustion Equipment

All combustion equipment installed must utilize a flue damper and electronic ignition except for domestic hot water heaters if flue damper, electronic ignition models are un-available. The utility and/or inspection branch having jurisdiction must be consulted on the proper sizing of the equipment and to ensure adequate air for combustion.

7. Furnace Rooms

Sealed furnace rooms must not be incorporated into the home design unless the furnace room design is approved by all authorities having jurisdiction in order to ensure that adequate combustion air exists and that the furnace room temperature is sufficient to prevent build up of moisture or ice in the furnace flue.

8. Water Heaters

"Heat Traps" must be installed on all water heaters.

At this point in the development of low energy construction techniques and building science technology, there is little agreement among the experts on what the optimum construction techniques, materials, and levels of airtightness and insulation should be. Recognizing this posture and that this program is designed to encourage builder innovation and creativity, the above criteria may be amended if changes are identified and agreed to in advance by Builder, Canada and Housing and Urban Development Association of Canada.

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            *               HOTCAN!               *
            * NATIONAL RESEARCH COUNCIL OF CANADA *
            *     DIVISION OF BUILDING RESEARCH    *
            *   SASKATOON, SASKATCHEWAN, 1982      *
            *       (RELEASE HOTCAN 4.00)          *
            * * * * * * * * * * * * * * * * * * * *

USER DATA FILE NAME: CROS12

DATA IS FOR FORT SMITH

                   *** BUILDING PARAMETERS ***
ELEMENTS          HOUSE       AIR            HT LOSS         % SEASONAL
                  VOLUME     CHANGE          W/DEGC          HT LOSS

VENTILATION     20950 FT3    .5/HR            91.51           54.21

                  AREA        R VALUE
                  FT2       FT2-DEGC/W

CEILING         1232.00        60.00
         TOTAL  1232.00        60.00          10.84            6.42

MAIN WALLS      1018.50        36.00
                 144.00        40.00
         TOTAL  1162.50        36.45          16.83            9.97

DOORS             28.00        10.00
         TOTAL    28.00        10.00           1.48             .88

BASEMENT AB.GD   538.00        37.00
         TOTAL   538.00        37.00           7.67            4.55

BASEMENT 2FT     288.00        40.00
         TOTAL   288.00        40.00           3.39            1.22

BASE. TO FLOOR   288.00        40.00
         TOTAL   288.00        40.00           3.39            1.22

FLOOR PERIMETER  396.00        20.00
         TOTAL   396.00        20.00           7.30            2.62

FLOOR CENTRE     836.00        20.00
         TOTAL   836.00        20.00          12.71            4.56

SOUTH WINDOWS     36.00         3.18
                   6.00         2.16
                  18.00         3.18
                  24.00         3.18
         TOTAL    84.00         3.08          14.40            8.53

NORTH WINDOWS     46.00         3.18
         TOTAL    46.00         3.18           7.62            4.52

EAST WINDOWS      13.50         3.18
         TOTAL    13.50         3.18           2.24            1.33
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WEST WINDOWS          .00          .00
         TOTAL        .00          .00              .00              .00

S-EAST WINDOWS        .00          .00
         TOTAL        .00          .00              .00              .00

S-WEST WINDOWS        .00          .00
         TOTAL        .00          .00              .00              .00

ADDRESS     : DAWSON CREEK

DESIGN HEAT LOSS AT  -43C =  10.2 KW
DEGREE DAYS FOR FORT SMITH IS  7852
TEMPERATURES (DEG C) MAIN FLOOR =  20   BASEMENT =  18
SENSIBLE HEAT GAIN FROM PEOPLE (KWH/D) =  0
DAILY BASE ELECTRIC CONSUMPTION (KWH/D) =  14
DAILY HOT WATER ENERGY CONSUMPTION (KWH/D) =  14
MASS LEVEL CHOSEN IS (A)
BASEMENT INSULATED PRIMARILY FROM THE INSIDE
WINDOW SHADING COEFFICIENTS: SOUTH  =  .73   NORTH  =  .72
                             EAST   =  .72   WEST   =  0
                             S-EAST =  0     S-WEST =  0
SOUTH OVERHANG GEOMETRY: AVERAGE WINDOW HEIGHT =  5 FT
                         AVERAGE OVERHANG WIDTH =  2 FT
                         AVERAGE HEIGHT ABOVE WINDOW =  .67 FT
NATURAL INFILTRATION RATE (AC/HR) =  .05
  FORCED VENTILATION RATE (AC/HR) =  .45

              *** MONTHLY SUMMARY OF ENERGY CONSUMPTION ***

MONTH           THERMAL LOAD    MONTHLY       AUX HEAT REQ   TOT CONS
                   KWH/D       SOLAR FRAC        KWH/D         KWH/D
JAN               164.22          .07           152.40        180.40
FEB               146.35          .15           125.10        153.10
MAR               120.69          .23            92.68        120.68
APR                74.07          .33            49.86         77.86
MAY                36.28          .48            18.75         46.75
JUN                14.48          .77             3.31         31.31
JUL                 4.90         1.00              .00         28.00
AUG                11.05          .94              .61         28.61
SEP                35.61          .41            21.17         49.17
OCT                62.46          .20            50.01         78.01
NOV               106.85          .09            97.01        125.01
DEC               144.39          .05           136.97        164.97

              *** YEARLY ENERGY CONSUMPTION COMPARISONS ***

12 MONTH HEATING SEASON IN EFFECT
ANNUAL SOLAR HEATING CONTRIBUTION =  19 %

ESTIMATED ANNUAL SPACE HEATING  81 GJ, OR              22,637 KWHRS
SEEH PROGRAM ENERGY BUDGET FOR SPACE HEATING =         15,162 KWHRS

PREDICTED ANNUAL AUXILIARY ENERGY CONSUMPTION =        10,220 KWHRS
SEEH PROGRAM AUXILIARY ENERGY CONSUMPTION =            10,600 KWHRS

TOTAL ANNUAL ENERGY CONSUMPTION =                      32,857 KWHRS
TOTAL ANNUAL SEEH PROGRAM ENERGY BUDGET =              25,762 KWHRS
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HOTCAN                                                      PAGE  3

                    *** ANNUAL PREDICTED FUEL COSTS ***

FUEL COSTS ARE FOR N.W.T.               AS OF 83/06/29

ENERGY           COST         SPACE          HOT            LIGHTS AND
SOURCE           PER UNIT     HEATING        WATER          APPLIANCES

PROPANE           37C/LITRE   $ 1682.7/YR    $ 483.42/YR
                               EFF.= 70%      EFF.= 55%         --


               ***********************************

         This estimate of energy demand may not reflect actual
     energy requirements of a house due to variations in
     weather, performance of equipment, and the lifestyle
     of the occupants.

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      *                HOTCAN!                 *
      * NATIONAL RESEARCH COUNCIL OF CANADA *
      *     DIVISION OF BUILDING RESEARCH      *
      *     SASKATOON, SASKATCHEWAN, 1982      *
      *        (RELEASE HOTCAN 4.00)           *
      * * * * * * * * * * * * * * * * * * * *


USER DATA FILE NAME: CROS2,2

DATA IS FOR FORT SMITH

                        *** BUILDING PARAMETERS ***
ELEMENTS                HOUSE      AIR              HT LOSS        % SEASONAL
                        VOLUME     CHANGE           W/DEGC         HT LOSS

VENTILATION            20950 FT3   .25/HR            46.21          37.41

                        AREA       R VALUE
                        FT2        FT2-DEGC/W

CEILING                1232.00       60.00
              TOTAL    1232.00       60.00           10.84           8.77

MAIN WALLS             1018.50       36.00
                        144.00       40.00
              TOTAL    1162.50       36.45           16.83          13.62

DOORS                    28.00       10.00
              TOTAL      28.00       10.00            1.48           1.20

BASEMENT AB.GD          538.00       37.00
              TOTAL     538.00       37.00            7.67           6.21

BASEMENT 2FT            288.00       40.00
              TOTAL     288.00       40.00            3.39           1.66

BASE. TO FLOOR          288.00       40.00
              TOTAL     288.00       40.00            3.39           1.66

FLOOR PERIMETER         396.00       20.00
              TOTAL     396.00       20.00            7.30           3.58

FLOOR CENTRE            836.00       20.00
              TOTAL     836.00       20.00           12.71           6.24

SOUTH WINDOWS            36.00        3.18
                          6.00        2.16
                         18.00        3.18
                         24.00        3.18
              TOTAL      84.00        3.08           14.40          11.65

NORTH WINDOWS            46.00        3.18
              TOTAL      46.00        3.18            7.62           6.17

EAST WINDOWS             13.50        3.18
              TOTAL      13.50        3.18            2.24           1.81
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HOTCAN                                                                  PAGE  2

WEST WINDOWS            .00           .00
         TOTAL          .00           .00              .00              .00

S-EAST WINDOWS          .00           .00
         TOTAL          .00           .00              .00              .00

S-WEST WINDOWS          .00           .00
         TOTAL          .00           .00              .00              .00

ADDRESS     : DAWSON CREEK

DESIGN HEAT LOSS AT  -43C =  7.3 KW
DEGREE DAYS FOR FORT SMITH IS  7852
TEMPERATURES (DEG C) MAIN FLOOR =  20   BASEMENT =  18
SENSIBLE HEAT GAIN FROM PEOPLE (KWH/D) =  0
DAILY BASE ELECTRIC CONSUMPTION (KWH/D) =  14
DAILY HOT WATER ENERGY CONSUMPTION (KWH/D) =  14
MASS LEVEL CHOSEN IS (A)
BASEMENT INSULATED PRIMARILY FROM THE INSIDE
WINDOW SHADING COEFFICIENTS: SOUTH  =  .73   NORTH  =  .72
                             EAST   =  .72   WEST   =  0
                             S-EAST =  0     S-WEST =  0
SOUTH OVERHANG GEOMETRY: AVERAGE WINDOW HEIGHT =  5 FT
                         AVERAGE OVERHANG WIDTH =  2 FT
                         AVERAGE HEIGHT ABOVE WINDOW =  .67 FT
NATURAL INFILTRATION RATE (AC/HR) =  .05
  FORCED VENTILATION RATE (AC/HR) =  .45
HEAT RECOVERY EFFECTIVENESS ON VENTILATION AIR =  55 %

              *** MONTHLY SUMMARY OF ENERGY CONSUMPTION ***

MONTH         THERMAL LOAD     MONTHLY       AUX HEAT REQ    TOT CONS
                 KWH/D        SOLAR FRAC        KWH/D          KWH/D
JAN             113.34           .10           101.52         129.52
FEB             100.91           .20            80.63         108.63
MAR              82.86           .32            56.46          84.46
APR              49.94           .44            27.97          55.97
MAY              23.12           .63             8.45          36.45
JUN               7.52          1.00              .00          28.00
JUL                .56          1.00              .00          28.00
AUG               4.75          1.00              .00          28.00
SEP              22.02           .60             8.76          36.76
OCT              41.04           .30            28.81          56.81
NOV              72.50           .14            62.66          90.66
DEC              99.17           .07            91.75         119.75

              *** YEARLY ENERGY CONSUMPTION COMPARISONS ***

12 MONTH HEATING SEASON IN EFFECT
ANNUAL SOLAR HEATING CONTRIBUTION =  24 %

ESTIMATED ANNUAL SPACE HEATING  50 GJ, OR           14,136 KWHRS
SEEH PROGRAM ENERGY BUDGET FOR SPACE HEATING =      15,162 KWHRS

PREDICTED ANNUAL AUXILIARY ENERGY CONSUMPTION =     10,220 KWHRS
SEEH PROGRAM AUXILIARY ENERGY CONSUMPTION =         10,600 KWHRS

TOTAL ANNUAL ENERGY CONSUMPTION =                   24,356 KWHRS
TOTAL ANNUAL SEEH PROGRAM ENERGY BUDGET =           25,762 KWHRS
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HOTCAN                                                            PAGE  3

                        *** ANNUAL PREDICTED FUEL COSTS ***

FUEL COSTS ARE FOR N.W.T.                       AS OF 83/06/29

ENERGY              COST          SPACE          HOT            LIGHTS AND
SOURCE              PER UNIT      HEATING        WATER          APPLIANCES

PROPANE              37C/LITRE    $ 1050.76/YR   $ 483.42/YR
                                    EFF.= 70%      EFF.= 55%         --


                    ***********************************

         This estimate of energy demand may not reflect actual
    energy requirements of a house due to variations in
    weather, performance of equipment, and the lifestyle
    of the occupants.

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              *                HOTCAN!                   *
              * NATIONAL RESEARCH COUNCIL OF CANADA *
              *    DIVISION OF BUILDING RESEARCH     *
              *    SASKATOON, SASKATCHEWAN, 1982     *
              *         (RELEASE HOTCAN 4.00)         *
              * * * * * * * * * * * * * * * * * * * *

USER DATA FILE NAME: CROS3,2

DATA IS FOR FORT SMITH

                        *** BUILDING PARAMETERS ***
ELEMENTS             HOUSE       AIR               HT LOSS          % SEASONAL
                     VOLUME     CHANGE             W/DEGC           HT LOSS

VENTILATION        20950 FT3    .13/HR              22.88             22.83

                     AREA        R VALUE
                     FT2        FT2-DEGC/W

CEILING            1232.00        60.00
          TOTAL    1232.00        60.00             10.84             10.82

MAIN WALLS         1018.50        36.00
                    144.00        40.00
          TOTAL    1162.50        36.45             16.83             16.80

DOORS                28.00        10.00
          TOTAL      28.00        10.00              1.48              1.47

BASEMENT AB.GD      538.00        37.00
          TOTAL     538.00        37.00              7.67              7.66

BASEMENT 2FT        288.00        40.00
          TOTAL     288.00        40.00              3.39              2.05

BASE. TO FLOOR      288.00        40.00
          TOTAL     288.00        40.00              3.39              2.05

FLOOR PERIMETER     396.00        20.00
          TOTAL     396.00        20.00              7.30              4.42

FLOOR CENTRE        836.00        20.00
          TOTAL     836.00        20.00             12.71              7.69

SOUTH WINDOWS        36.00         3.18
                      6.00         2.16
                     18.00         3.18
                     24.00         3.18
          TOTAL      84.00         3.08             14.40             14.37

NORTH WINDOWS        46.00         3.18
          TOTAL      46.00         3.18              7.62              7.61

EAST WINDOWS         13.50         3.18
          TOTAL      13.50         3.18              2.24              2.23
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HOTCAN                                                          PAGE  2

WEST WINDOWS            .00          .00
         TOTAL          .00          .00            .00            .00

S-EAST WINDOWS          .00          .00
         TOTAL          .00          .00            .00            .00

S-WEST WINDOWS          .00          .00
         TOTAL          .00          .00            .00            .00

ADDRESS     : DAWSON CREEK

DESIGN HEAT LOSS AT  -43C =  5.8 KW
DEGREE DAYS FOR FORT SMITH IS  7852
TEMPERATURES (DEG C) MAIN FLOOR =  20   BASEMENT =  18
SENSIBLE HEAT GAIN FROM PEOPLE (KWH/D) =  3.2
DAILY BASE ELECTRIC CONSUMPTION (KWH/D) =  14
DAILY HOT WATER ENERGY CONSUMPTION (KWH/D) =  14
MASS LEVEL CHOSEN IS (A)
BASEMENT INSULATED PRIMARILY FROM THE INSIDE
WINDOW SHADING COEFFICIENTS: SOUTH  =  .73   NORTH  =  .72
                             EAST   =  .72   WEST   =  0
                             S-EAST =  0     S-WEST =  0
SOUTH OVERHANG GEOMETRY: AVERAGE WINDOW HEIGHT =  5 FT
                         AVERAGE OVERHANG WIDTH =  2 FT
                         AVERAGE HEIGHT ABOVE WINDOW =  .67 FT
NATURAL INFILTRATION RATE (AC/HR) =  .05
  FORCED VENTILATION RATE (AC/HR) =  .25
HEAT RECOVERY EFFECTIVENESS ON VENTILATION AIR =  70 %

            *** MONTHLY SUMMARY OF ENERGY CONSUMPTION ***

MONTH          THERMAL LOAD    MONTHLY       AUX HEAT REQ   TOT CONS
                  KWH/D       SOLAR FRAC        KWH/D        KWH/D
JAN               83.93          .14            72.11        100.11
FEB               74.30          .26            54.77         82.77
MAR               60.17          .41            35.65         63.65
APR               34.30          .56            15.02         43.02
MAY               13.14          .83             2.29         30.29
JUN                 .74         1.00              .00         28.00
JUL                 .00         1.00              .0C         28.00
AUG                 .00         1.00              .00         28.00
SEP               11.82          .87             1.55         29.55
OCT               26.81          .44            15.05         43.05
NOV               51.60          .19            41.76         69.76
DEC               72.67          .10            65.25         93.25

            *** YEARLY ENERGY CONSUMPTION COMPARISONS ***

12 MONTH HEATING SEASON IN EFFECT
ANNUAL SOLAR HEATING CONTRIBUTION =  29 %

ESTIMATED ANNUAL SPACE HEATING  33 GJ, OR              9,184 KWHRS
SEEH PROGRAM ENERGY BUDGET FOR SPACE HEATING =        15,162 KWHRS

PREDICTED ANNUAL AUXILIARY ENERGY CONSUMPTION =       10,220 KWHRS
SEEH PROGRAM AUXILIARY ENERGY CONSUMPTION =           10,600 KWHRS

TOTAL ANNUAL ENERGY CONSUMPTION =                     19,404 KWHRS
TOTAL ANNUAL SEEH PROGRAM ENERGY BUDGET =             25,762 KWHRS
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                   *** ANNUAL PREDICTED FUEL COSTS ***

FUEL COSTS ARE FOR N.W.T.               AS OF 83/06/29

ENERGY           COST          SPACE          HOT             LIGHTS AND
SOURCE           PER UNIT      HEATING        WATER           APPLIANCES

PROPANE           37C/LITRE    $ 682.7/YR     $ 483.42/YR
                                EFF.= 70%      EFF.= 55%          --


               ***********************************

          This estimate of energy demand may not reflect actual
     energy requirements of a house due to variations in
     weather, performance of equipment, and the lifestyle
     of the occupants.

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LOG VERSUS FRAME HOUSING

BY

AXEL R. CARLSON
UNIVERSITY OF ALASKA
FAIRBANKS, ALASKA

LOG VERSUS FRAME HOUSE

by

Axel R. Carlson

The need for conservation of energy necessitates a more careful look at the thermal properties of building materials. Unfortunately, the failure to review existing information on thermal properties of wood has resulted in the underrating of the insulation values of a log house. Also, the failure to include the framing members in the thermal analysis of a frame wall has resulted in the overrating of the insulation value of a frame house.

LITERATURE SEARCH

ASHRAE rates the R-value of soft wood in English units as 1.25 (Metric units AS 0.22) based on a laboratory measurement of 12-15% moisture content under steady state conditions(1). Finnish sauna experts state that timber under normal operations may reach an equilibrium moisture content of 0.5-2.0%(2). Therefore, it is estimated that soft wood would have an R-value of 1.55 at 5% moisture content(3).

Wood maintained at a constant temperature of 70°F (38.8°C) and a relative humidity of 60% may reach an equilibrium moisture content of 12%(4). If a house were kept at a relative humidity of 60%, serious condensation problems would occur, particularly in the colder winter climates of Canada and Alaska. A vapor pressure differential of 17.6 to 26.5 pounds per square foot would occur at an indoor temperature of 65°F, respective outdoor temperatures of -60 to 30°F at an average outdoor humidity of 75%(5).

Current HUD Minimum Property Standards specify a minimum R-value of 12.5 for exterior walls, which is based on a 2x4 stud wall with 3½" of fiberglass. Presumably it excludes the heat loss of studs and extra framing members around windows, doors, etc.

A new method of evaluating the insulating properties of wall sections has been included in the New Mexico Energy Conservation Code, which rates the insulation value of wall section as "effective U-value". It results in a lower heat loss than the ASHRAE "steady state" values(6). The effective U-value varies with climatic regions, solar orientation and color of paint. It appears, from reviewing the data, that the heat loss becomes less with greater specific heat of higher density materials such as logs. Also, the effective U-value increases with lower heating degree days and with the higher solar heat gain of warmer climates such as New Mexico. At this time, it is not known how the specific heat will improve the effective U-value of building material in colder climates of Canada and Alaska.

The thermal properties of common building materials extrapolated from several reference books are summarized in Table 1, which includes the specific gravity, density, insulation values and specific heat in English and Metric units of measurement.

LOG VERSUS FRAME WALL

A tabulation of the thermal coefficients of a 2x4 stud wall insulated with 3½" of fiberglass has an average English R-value of 12.08 (Metric R-value 2.13) at a 16" stud spacing - Table 2.2. This data is based on 5/8" textured plywood exterior siding and ½" sheet rock with thermal values as listed in the table. Field counts indicate that studs spaced at 16" centers may average as low as 8" centers, when counting double or triple studs around windows and doors, corner

Professor Emeritus, Co-operative Extension Service, University of Alaska, Fairbanks, Ak. 99701

posts, interior partitions, etc. This is a gross waste of labor, material and energy costs based on today's energy conservation needs. An average stud spacing of 8" would result in an average R-value of 11.40 (2.01), while a true spacing of 16" would result in an R-value of 12.08 (2.13). If the studs were spaced 24" on center with single studs around windows and doors, the insulated wall would have an R-value of 12.32 (2.17).

The weight of the 2x4 wall at various stud spacings is listed in Table 2.1. Also, the specific heat is tabulated in Table 2.3.

None of the above R-values would meet HUD's minimum standards, unless the wall was sheathed with insulation board. In Alaska, plywood sheathing is preferred over insulation board as it has greater shear strength as confirmed by an inspection of damage to buildings in the 1964 Alaska earthquake.

Even a 2x6 stud and a double 2x4 stud superinsulated wall may have stud spacings of as little as 8", which is a gross waste of material and energy. This occurs because designers persist in placing windows and doors at a prescribed distance from some reference point without taking into account the conventional 16" or 24" method of spacing studs. HUD standards have approved 24" spacing of studs with plywood sheathing or diagonal bracing. Designers should show an elevation of exterior walls for more efficient spacing of studs and placement of window and door openings. Modular windows of 24" or 48" widths should be used with a full 24" spacing of studs.

Sweden was one of the first known countries to use 24" stud spacings with single studs around windows and doors instead of double or triple trimmer studs. Arkansas, in an effort to reduce building and heating costs, was one of the first States to follow the Scandinavian wall framing system. Arkansas adopted the insulated box beam headers instead of solid or laminated members. The junction of the interior partition with the outer wall no longer requires double framed studs to support the sheet rock; instead, the sheet rock is supported with special metal clips.

The average insulation values of a 2x6 stud wall with 5½" fiberglass is tabulated in Table 3.2. A stud spacing of 8" would result in an average R-value of 17.45 (3.07), while a 16" spacing would result in an R-value of 18.79 (3.31) and 24" spacing would result in an R-value of 19.28 (3.40).

The weight of the 2x6 stud wall with 5½" of fiberglass at various stud spacings is listed in Table 3.1. The specific heat of the wall is shown in Table 3.3.

Most building codes recommend a minimum window area of 10% of the floor area. Arkansas, with the need for energy conservation, has reduced the minimum window area from 10% to 8%. The Alaska State Housing Authority has erected low-cost housing in "bush" areas with as little as 5% window area. A survey of USDA house plans several years ago indicated window areas varying between 13.9% and 17.8%. An upper middle class home may have window areas in excess of 25%. Log house builders may select window areas around 5-8% to reduce labor and material costs. Also, smaller window and door openings in a log wall increases its rigidity.

The more careful sizing of windows for a log house may result in lower heat losses than a frame wall house with a higher thermal value. The effect of windows on the total heat loss of a 24 x 48 one-story house with a daylite basement is summarized in Tables 4.1 and 4.2. For example, a framed wall house with 25% window area (15% and 10%) and insulated with 6" of fiberglass (R = 17.45) would have a structural heat loss of 405.6 Btu/hour-F (2.30 kW/hour-C). A log house constructed of 3-SQ 6" logs (R = 9.30) with only 15% window area (5% + 10%) would have a structural heat loss of 387.4 Btu/hour-F (2.20 kW/hour-C). Increasing the insulation thickness from 12" to 18" would reduce the heat loss from 31.2 to 20.4 Btu/hour-F. Reducing the window area from 15% to 10% would reduce the heat loss from 94.0 to 62.5 Btu/hour-F, for a savings of 31.5 Btu/hour-F.

The average thermal values of different types of walls are summarized in Table 5. A 2x4 stud wall insulated by 3½" fiberglass with a stud spacing of 24" would have a specific heat of 2.24 Btu/ft.^{o}2 - F (12.71 W/m^{o}2 - C) as compared to a 9" milled log with a specific heat of 25.36 Btu/ft.^{o}2 - F (143.90 W/m^{o}2 - C). The stud wall has an R-value of 12.08 as compared to 12.32 for the 9" milled log wall. A concrete block wall would have a specific heat of 75.08 Btu/hour/ft.^{o}2-F (426.07 W/m^{o}2-F) and an R-value of only 2.2. The effect of thermal mass on the "effective U-values" of wall sections in cold climates such as Alaska has not been determined.

CONCLUSIONS

In order to compare thermal value of a log house against a stud frame house, a complete heat loss analysis should be conducted to determine the effect of the heat loss of all exposed surfaces.

It is recommended that the average insulation of all exposed floor, wall and roof surfaces, rather than attempting to evaluate insulation values of a house based on a single surface such as the wall, be taken into account.

Deficiencies in thermal properties of walls can be made up by installing thicker insulation in the roof with little extra cost, particularly a truss roof.

The effective insulation value of a wall can be increased substantially by more judicious sizing and placement of windows. Solar gain through glass can be improved by maximum use of south-facing windows.

To avoid extra studs in a wall due to windows and doors, it is strongly recommended that the designer draw an elevation of each wall to develop the most efficient use of labor, materials and energy.

REFERENCES

1. ASHRAE, Handbook of Fundamentals, 1976.
2. Allan Konya, et al., The International Handbook of Finnish Sauna, John Wiley and Sons, New York, 1973.
3. Axel R. Carlson, Thermal Properties of Walls, pp 4-756, Co-operative Extension Service, University of Alaska, Fairbanks, Alaska, 1976.
4. Timber Engineering Co., Timber Design and Construction Handbook, F. W. Corporation, New York, 1956.
5. Axel R. Carlson, Vapor Barrier Design for Closed Buildings, 82-4525, American Society of Agricultural Engineers, Chicago, Ill., 1982.
6. James O. Dritt, The Energy Conservation Code, New Mexico Application, Chapter 53, New Mexico Energy Institute, The University of New Mexico, Albuquerque, 1978.

TABLE 1. PROPERTIES OF COMMOM BUILDING MATERIALS

Axel R. Carlson

MATERIAL	* DENSITY *		INSULATION VALUES				SPECIFIC HEAT		
	* METRIC *	ENGLISH *	ENGLISH			* METRIC *	ENGLISH		* METRIC
	g/m°3	lb/ft°3	Btu/hr-ft-F	Btu/hr-ft°2-in-F	R-value (1)	W/m-K	Btu/lb-R	Btu/in-F	kJ/kg-K
Asbestos cement board 1"	1.40	87.4	.350	4.200	.24	.606	.20	1.456	.837
Brick comon 1"	1.75	109.2	.420	5.040	.20	.727	.22	2.002	.920
Brick face 1"	2.00	124.8	.750	9.000	.11	1.298	.24	2.496	1.004
Concrete gypsum fiber 1"	.78	48.7	.250	3.000	.33	.433	.23	.933	.962
Concrete sand-gravel 1"	2.20	137.3	1.000	12.000	.08	1.731	.18	2.059	.753
Cork board 1"	.20	12.5	.025	.300	3.33	.043	.45	.468	1.883
Fiberglass 2.25"	.01	.9	.027	.321	7.00	.046	.20	.015	.837
Fiberglass 3.50"	.01	.8	.027	.318	11.00	.046	.20	.013	.837
Fiberglass 5.50"	.01	.8	.024	.289	19.00	.042	.20	.014	.837
Fiberglass 7.00"	.01	.8	.027	.318	22.00	.046	.20	.013	.837
Fiberglass 9.00"	.01	.8	.025	.300	30.00	.043	.20	.013	.837
Fiberglass 11.00"	.01	.8	.024	.289	38.00	.042	.20	.014	.837
Fiberglass 16.50"	.01	.8	.024	.289	57.00	.042	.20	.014	.837
Glass solid 1"	2.50	156.0	.550	6.600	.15	.952	.20	2.600	.837
Gypsum board 1"	.80	49.9	.100	1.200	.83	.173	.26	1.082	1.088
Ice (32 F) 1"	.90	56.2	1.250	15.000	.07	2.163	.50	2.340	2.092
Plaster cement sand 1"	1.80	112.3	.150	1.800	.56	.260	.22	2.059	.920
Plywood 1"	.61	38.1	.800	9.600	.10	1.385	.60	1.903	2.510
Polystyrene expanded cut 1"	.03	1.8	.021	.250	4.00	.036	.29	.044	1.213
Polystyrene expanded smooth 1"	.04	2.2	.017	.200	5.00	.029	.29	.053	1.213
Polystyrene expanded smooth 1"	.05	3.5	.016	.190	5.26	.027	.29	.085	1.213
Polystyrene expAnded bead 1"	.02	1.0	.023	.280	3.57	.040	.29	.024	1.213
Polyurethane expanded 1"	.02	1.5	.013	.160	6.25	.023	.38	.048	1.590
Sawdust 1"	.15	9.4	.050	.600	1.67	.087	.21	.164	.879
Vermiculite 1"	.13	8.1	.035	.420	2.38	.061	.20	.135	.837
Water (100 F) 1"	1.00	62.4	.363	4.356	.23	.628	1.00	5.190	4.176
Wood. oak, maple 15 % MC 1"	.72	44.9	.100	1.200	.83	.173	.70	2.621	2.929
Wood, pine, fir, 15 % MC 1"	.51	31.8	.067	.800	1.25	.115	.60	1.591	2.510
Wood, pine, fir, 5 % MC 1"	.49	30.6	.053	.636	1.57	.092	.50	1.274	2.092

(1) For thickness listed.

Extrapolated from: a. Handbook of Tables of Applied Engineering Science, The Chemical Rubber Co, Cleveland, 1972
b. Engineering Manual, John H. Perry, etal, McGraw-Hill Book Co, Ney York, 1959
c. Handbook of Fundementals, American Society Heating, Refrigerating amd Air Conditioning Engineers, 1977
d. Owens/Corning Fiberglass, Pub. No. 5-bl-6453, 1974

Professor Emeritus, Co-operative Extension Service, University of Alaska, Fairbanks, Ak.99701

TABLE 2-1. WEIGHT 2X4 STUD WALL, 3-1/2" FIBERGLASS

Axel R. Carlson

SPACING Inch	STUDS Number	FRAME ft*2	FRAME lb	INSULATION ft*2	INSULATION lb	SHEET ROCK ft*2	SHEET ROCK lb	PLYWOOD ft*2	PLYWOOD lb	TOTAL lb	UNIT lb/ft*2	UNIT kg/m*2
1.5	64.0	64.0	593.6	.0	.0	64.0	133.1	64.0	127.0	853.7	13.34	65.12
2.0	48.0	48.8	452.2	15.3	3.6	64.0	133.1	64.0	127.0	715.8	11.18	54.61
4.0	24.0	25.9	240.0	38.1	8.9	64.0	133.1	64.0	127.0	509.0	7.95	38.83
6.0	16.0	18.3	169.3	45.8	10.7	64.0	133.1	64.0	127.0	440.0	6.88	33.57
8.0	12.0	14.4	133.9	49.6	11.6	64.0	133.1	64.0	127.0	405.6	6.34	30.94
10.0	9.6	12.2	112.7	51.9	12.1	64.0	133.1	64.0	127.0	384.9	6.01	29.36
12.0	8.0	10.6	98.6	53.4	12.5	64.0	133.1	64.0	127.0	371.1	5.80	28.31
14.0	6.9	9.5	88.5	54.5	12.7	64.0	133.1	64.0	127.0	361.3	5.64	27.56
16.0	6.0	8.7	80.9	55.3	12.9	64.0	133.1	64.0	127.0	353.8	5.53	26.99
18.0	5.3	8.1	74.9	55.9	13.0	64.0	133.1	64.0	127.0	348.1	5.44	26.55
20.0	4.8	7.6	70.2	56.4	13.2	64.0	133.1	64.0	127.0	343.4	5.37	26.20
22.0	4.4	7.2	66.4	56.8	13.3	64.0	133.1	64.0	127.0	339.7	5.31	25.92
24.0	4.0	6.8	63.2	57.2	13.3	64.0	133.1	64.0	127.0	336.6	5.26	25.68
.0	.0	.0	.0	64.0	14.9	64.0	133.1	64.0	127.0	275.0	4.30	20.98

CONSTANTS:	WEIGHT, lb/ft*3	THICK, in
STUD	31.80	3.500
FIBERGLASS	.80	3.500
SHEET ROCK	49.90	.500
PLYWOOD	38.10	.625

CONVERSION:
lb/ft*2 X 4.8824 = kg/m*2

B:2X4WGHT.CAL, A1:M36, 09-04-83, REVISED 9/26/83

Professor Emeritus, Co-operative Extension Service, University of Alaska, Fairbanks, Ak.99701

TABLE 2-2. AVERAGE INSULATION VALUE SINGLE 2X4 STUD WALL, 3-1/2" FIBERGLASS

Axel R. Carlson

STUD SPACING		FRAMED		INSULATED		TOTAL	ENGLISH		METRIC	
Inches	Number	ft*2	Btu/ hr-F	ft*2	Btu/ hr-F	Btu/ hr-F	Btu/ hr-ft*2-F	R-value	W/ m*2-C	R-value
1.5	64.0	64.00	8.32	.00	.00	8.32	.1300	7.69	.7375	1.36
2.0	48.0	48.75	6.34	15.25	1.15	7.49	.1170	8.55	.6637	1.51
4.0	24.0	25.88	3.36	38.13	2.87	6.24	.0974	10.26	.5529	1.81
6.0	16.0	18.25	2.37	45.75	3.45	5.82	.0909	11.00	.5160	1.94
8.0	12.0	14.44	1.88	49.56	3.74	5.61	.0877	11.40	.4976	2.01
10.0	9.6	12.15	1.58	51.85	3.91	5.49	.0857	11.66	.4865	2.06
12.0	8.0	10.63	1.38	53.38	4.02	5.40	.0844	11.84	.4791	2.09
14.0	6.9	9.54	1.24	54.46	4.10	5.34	.0835	11.98	.4738	2.11
16.0	6.0	8.72	1.13	55.28	4.17	5.30	.0828	12.08	.4699	2.13
18.0	5.3	8.08	1.05	55.92	4.21	5.26	.0823	12.16	.4668	2.14
20.0	4.8	7.50	.98	56.43	4.25	5.24	.0818	12.22	.4643	2.15
22.0	4.4	7.16	.93	56.84	4.28	5.21	.0815	12.27	.4623	2.16
24.0	4.0	6.81	.89	57.19	4.31	5.20	.0812	12.32	.4606	2.17
.0	.0	.00	.00	64.00	4.82	4.82	.0754	13.27	.4277	2.34

DIMENSIONS:		R-VALUES:		CONVERSION:		
Panel width, ft	8.00	Stud/In	1.55	BTU/ hr-ft*2-F	X 5.6745	= W/ M*2-K
Panel height, Ft	8.00	Fiberglass 3_1/2"	11.00			
Panel, Sgl=1,dbl=2	1.00	Fiberglass 0" 2nd	.00			
Sole, No	1.00	Sheetrock 1/2"	.45			
Plate, No.	2.00	Plywood 5/8" R1.55	.97			
Stud width, In	1.50	Exterior film 15M	.17			
Stud depth, In	3.50	Interior film	.68			

B:S2X4INS.CAL, A1:K41, 09-12-83, REVISED 9/24/83

Professor Emeritus, Co-operative Extension Service, University of Alaska, Fairbanks, Ak. 99701

TABLE 2-3. SPECIFIC HEAT 2X4 STUD WALL, 3-1/2" FIBERGLASS

Axel R. Carlson

SPACING Inch	STUDS Number	FRAME ft*2	FRAME Btu/F	INSULATION ft*2	INSULATION Btu/F	SHEET ROCK ft*2	SHEET ROCK Btu/F	PLYWOOD ft*2	PLYWOOD Btu/F	TOTAL Btu/F	UNIT Btu/ ft*2-F	UNIT W/ M*2-C
1.5	64.0	64.0	284.5	.0	.0	64.0	34.6	64.0	76.0	395.0	6.17	35.03
2.0	48.0	48.8	216.7	15.3	.7	64.0	34.6	64.0	76.0	327.9	5.12	29.08
4.0	24.0	25.9	115.0	38.1	1.7	64.0	34.6	64.0	76.0	227.3	3.55	20.16
6.0	16.0	18.3	81.1	45.8	2.1	64.0	34.6	64.0	76.0	193.8	3.03	17.18
8.0	12.0	14.4	64.2	49.6	2.3	64.0	34.6	64.0	76.0	177.0	2.77	15.69
10.0	9.6	12.2	54.0	51.9	2.4	64.0	34.6	64.0	76.0	166.9	2.61	14.80
12.0	8.0	10.6	47.3	53.4	2.4	64.0	34.6	64.0	76.0	160.2	2.50	14.21
14.0	6.9	9.5	42.4	54.5	2.5	64.0	34.6	64.0	76.0	155.4	2.43	13.78
16.0	6.0	8.7	38.8	55.3	2.5	64.0	34.6	64.0	76.0	151.8	2.37	13.46
18.0	5.3	8.1	35.9	55.9	2.5	64.0	34.6	64.0	76.0	149.0	2.33	13.21
20.0	4.8	7.6	33.6	56.4	2.6	64.0	34.6	64.0	76.0	146.8	2.29	13.01
22.0	4.4	7.2	31.8	56.8	2.6	64.0	34.6	64.0	76.0	145.0	2.27	12.85
24.0	4.0	6.8	30.3	57.2	2.6	64.0	34.6	64.0	76.0	143.4	2.24	12.72
.0	.0	.0	.0	64.0	2.9	64.0	34.6	64.0	76.0	113.5	1.77	10.06

SPECIFIC HEAT, Btu/in-ft*2-F		THICK, in
STUD, FIR	1.270	3.500
FIBERGLASS	.013	3.500
SHEET ROCK	1.080	.500
PLYWOOD	1.900	.625

CONVERSION:

Btu/ft*2 x 5.6745 = W/m*2-K

B:2X4SPCH.CAL, A1:M37, 09-04-83, REVISED 9/24/83

Professor Emeritus, Co-cperative Extension Service, University of Alaska, Fairbanks, Ak. 99701

TABLE 3-1. WEIGHT 2X6 STUD WALL, 5-1/2" FIBERGLASS

Axel R. Carlson

SPACING	STUDS	FRAME		INSULATION		SHEET ROCK		PLYWOOD		TOTAL	UNIT	
Inch	Number	ft*2	lb	ft*2	lb	ft*2	lb	ft*2	lb	lb	lb/ft*2	kg/m*2
1.5	64.0	64.0	932.8	.0	.0	64.0	133.1	64.0	127.0	1,192.9	18.64	91.00
2.0	48.0	48.8	710.5	15.3	5.6	64.0	133.1	64.0	127.0	976.2	15.25	74.47
4.0	24.0	25.9	377.2	38.1	14.0	64.C	133.1	64.0	127.0	651.2	10.18	49.68
6.0	16.0	18.3	266.0	45.8	16.8	64.0	133.1	64.0	127.0	542.8	8.48	41.41
8.0	12.0	14.4	210.5	49.6	18.2	64.0	133.1	64.0	127.0	488.7	7.64	37.28
10.0	9.6	12.2	177.1	51.9	19.0	64.0	133.1	64.0	127.0	456.2	7.13	34.80
12.0	8.0	10.6	154.9	53.4	19.6	64.0	133.1	64.0	127.0	434.6	6.79	33.15
14.0	6.9	9.5	139.0	54.5	20.0	64.0	133.1	64.0	127.0	419.1	6.55	31.97
16.0	6.0	8.7	127.1	55.3	20.3	64.0	133.1	64.0	127.0	407.4	6.37	31.08
18.0	5.3	8.1	117.8	55.9	20.5	64.0	133.1	64.0	127.0	398.3	6.22	30.39
20.0	4.8	7.6	110.3	56.4	20.7	64.0	133.1	64.0	127.0	391.1	6.11	29.84
22.0	4.4	7.2	104.4	56.8	20.8	64.0	133.1	64.0	127.0	385.3	6.02	29.39
24.0	4.0	6.8	99.3	57.2	21.0	64.0	133.1	64.0	127.0	380.3	5.94	29.01
.0	.0	.0	.0	64.0	23.5	64.0	133.1	64.0	127.0	283.5	4.43	21.63

CONSTANTS:	WEIGHT, lb/ft*3	THICK, in
STUD	31.80	5.500
FIBERGLASS	.80	5.500
SHEET ROCK	49.90	.500
PLYWOOD	38.10	.625

CONVERSION:

lb/ft*2 X 4.8824 = kg/m*2

B:2X6WGHT.CAL, A1:M36, 09-04-83, REVISED 9/24/83

Professor Emeritus, Co-operative Extension Service, University of Alaska, Fairbanks, Ak. 99701

TABLE 3-2. AVERAGE INSULATION VALUE SINGLE 2X6 STUD WALL, 5-1/2" FIBERGLASS

Axel R. Carlson

STUD SPACING		FRAMED		INSULATED		TOTAL	ENGLISH		METRIC	
Inch	Number	ft*2	Btu/ hr-F	ft*2	Btu/ hr-F	Btu/ hr-F	Btu/ hr-ft*2-F	R-value	W/ m*2-C	R-value
1.5	64.0	64.00	5.93	.00	.00	5.93	.0926	10.79	.5257	1.90
2.0	48.0	48.75	4.52	15.25	.72	5.23	.0818	12.23	.4640	2.16
4.0	24.0	25.88	2.40	38.13	1.79	4.19	.0655	15.28	.3715	2.69
6.0	16.0	18.25	1.69	45.75	2.15	3.84	.0600	16.66	.3406	2.94
8.0	12.0	14.44	1.34	49.56	2.33	3.67	.0573	17.45	.3252	3.07
10.0	9.6	12.15	1.13	51.85	2.44	3.56	.0557	17.96	.3160	3.17
12.0	8.0	10.63	.98	53.38	2.51	3.49	.0546	18.32	.3098	3.23
14.0	6.9	9.54	.88	54.46	2.56	3.44	.0538	18.58	.3054	3.27
16.0	6.0	8.72	.81	55.28	2.60	3.41	.0532	18.79	.3021	3.31
18.0	5.3	8.08	.75	55.92	2.63	3.38	.0528	18.95	.2995	3.34
20.0	4.8	7.58	.70	56.43	2.65	3.35	.0524	19.08	.2974	3.36
22.0	4.4	7.16	.66	56.84	2.67	3.34	.0521	19.19	.2958	3.38
24.0	4.0	6.81	.63	57.19	2.69	3.32	.0519	19.28	.2944	3.40
.0	.0	.00	.00	64.00	3.01	3.01	.0470	21.27	.2668	3.75

DIMENSIONS:		R-VALUES:	
Panel width, ft	8.00	Stud/In	1.55
Panel height, ft	8.00	Fiberglass 5-1/2"	19.00
Panel, Sgl=1,dbl=2	1.00	Fiberglass 0	.00
Sole, No	1.00	Sheetrock 1/2"	.45
Plate, No.	2.00	Plywood 5/8" R-1.5	.97
Stud width, In	1.50	Exterior film 15M	.17
Stud depth, In	5.50	Interior film	.68

CONVERSION:
Btu/ hr-sf-F X 5.6745 = W/ m*2-C

B:S2X6INS.CAL, A1:K41, 09-12-83 REVISED 9/24/83

Professor Emeritus, Co-operative Extension Service, University of Alaska, Fairbanks, Ak. 99701

TABLE 3-3. SPECIFIC HEAT 2X6 STUD WALL, 5-1/2" FIBERGLASS

Axel R. Carlson

SPACING	STUDS	FRAME		INSULATION		SHEET ROCK		PLYWOOD		TOTAL	UNIT	
Inch	Number	ft*2	Btu/F	ft*2	Btu/F	ft*2	Btu/F	ft*2	Btu/F	Btu/F	Btu/ ft*2-F	W/ M*2-C
1.5	64.0	64.0	447.0	.0	.0	64.0	34.6	64.0	76.0	557.6	8.71	49.44
2.0	48.0	48.8	340.5	15.3	1.1	64.0	34.6	64.0	76.0	452.2	7.07	40.09
4.0	24.0	25.9	180.8	38.1	2.7	64.0	34.6	64.0	76.0	294.1	4.59	26.07
6.0	16.0	18.3	127.5	45.8	3.3	64.0	34.6	64.0	76.0	241.3	3.77	21.40
8.0	12.0	14.4	100.9	49.6	3.5	64.0	34.6	64.0	76.0	215.0	3.36	19.06
10.0	9.6	12.2	84.9	51.9	3.7	64.0	34.6	64.0	76.0	199.1	3.11	17.66
12.0	8.0	10.6	74.3	53.4	3.8	64.0	34.6	64.0	76.0	188.6	2.95	16.72
14.0	6.9	9.5	66.6	54.5	3.9	64.0	34.6	64.0	76.0	181.1	2.83	16.06
16.0	6.0	8.7	60.9	55.3	4.0	64.0	34.6	64.0	76.0	175.4	2.74	15.55
18.0	5.3	8.1	56.4	55.9	4.0	64.0	34.6	64.0	76.0	171.0	2.67	15.16
20.0	4.8	7.6	52.9	56.4	4.0	64.0	34.6	64.0	76.0	167.5	2.62	14.85
22.0	4.4	7.2	50.0	56.8	4.1	64.0	34.6	64.0	76.0	164.6	2.57	14.60
24.0	4.0	6.8	47.6	57.2	4.1	64.0	34.6	64.0	76.0	162.2	2.53	14.38
.0	.0	.0	.0	64.0	4.6	64.0	34.6	64.0	76.0	115.1	1.80	10.21

SPECIFIC HEAT, Btu/in-ft*2-F		THICK, in
STUD, FIR	1.270	5.500
FIBERGLASS	.013	5.500
SHEET ROCK	1.080	.500
PLYWOOD	1.900	.625

CONVERSION:
Btu/ft*2 x 5.6745 = W/m*2-K

B:2X6SPCH.CAL, A1:M37, 09-04-83, REVISED 9/24/83

Professor Emeritus, Co-operative Extension Service, University of Alaska, Fairbanks, Ak. 99701

TABLE 4-1. EFFECT OF WINDOWS ON HEAT LOSS

Axel R. Carlson

HOUSE, 24-0X48-0, 1-STORY, DAYLITE BASEMENT

SURFACE LOSSES	R-VALUE	AREA ft*2	LOSS Btu/ HR-F	AREA ft*2	LOSS Btu/ hr-F	AREA ft*2	LOSS Btu/ hr-F	AREA ft*2	LOSS Btu/ hr-F	AREA ft*2	LOSS Btu/ hr-F
BASEMENT/FOUNDATION:	(Window)	5-0	pct	5-0	pct	5-0	pct	5-0	pct	5-0	pct
FLOOR 0 INS	27.00	1,152	42.7	1,152	42.7	1,152	42.7	1,152	42.7	1,152	42.7
WALL BELOW 2 STY	16.70	487	29.2	1,152	29.2	487	29.2	487	29.2	487	29.2
WINDOW SOUTH DBL	1.84	58	31.5	58	31.5	58	31.5	58	31.5	58	31.5
WINDOW OTHER DBL	1.84										
DOOR PEDESTRIAN	11.17	20	1.8	20	1.8	20	1.8	20	1.8	20	1.8
DOOR GARAGE	11.17	128	11.5	128	11.5	128	11.5	128	11.5	128	11.5
WALL ABOVE BLK 2ST	13.20	517	39.2	517	39.1	517	39.1	517	39.1	517	39.1
SUBTOTAL	15.16	2,362	155.8	2,362	155.8	2,362	155.8	2,362	155.8	2,362	155.8
FIRST FLOOR:	(Window)	3-2	pct	6-4	pct	9-6	Pct	12-8	Pct	15-10	pc
FLOOR WARM	N/A	1,152	N/A	1,152	N/A	1,152	N/A	1152	N/A	1,152	N/A
WINDOW SOUTH DBL	1.84	35	19.0	69	37.5	104	56.5	138	75.0	172	93.5
WINDOW OTHER DBL	1.84	23	12.5	46	25.0	69	37.5	92	50.0	115	62.5
DOOR PEDESTRIAN	11.17	40	3.6	40	3.6	40	3.6	40	3.6	40	3.6
WALL 2X4 3.5 FG 8 OC	10.83	1,054	97.3	997	92.1	939	86.7	882	81.4	824	76.1
GABLE	12.21	144	11.8	144	11.8	144	11.8	144	11.8	144	11.8
CEILING 12" FG	38.00	1,187	31.2	1,187	31.2	1,187	31.2	1187	31.2	1,187	31.2
SUBTOTAL	14.15	2,483	175.5	2,483	201.2	2,483	227.3	2483	253.1	2,482	278.7
TOTAL STRUCTURAL	14.63	4,845	331.2	4,845	357.0	4,845	383.1	4,845	408.8	4,844	434.4
INFILTRATION LOSSES		cfm	Btu/ hr-F	cfm	Btu/ hr-F	cfm	Btu/ hr-F	cfm	Btu/ hr-F	cfm	Btu/ hr-F
		61	66.7	61	66.7	61	66.7	61	66.7	61	66.7
GRAND TOTAL			397.9		423.6		449.8		475.5		501.1

B:HET-LOG.CAL, A1:L64, 09-01-83, REV 9/26/

Professor Emeritus, Co-operative Extension Service, University of Alaska, Fairbanks, Ak. 99701

TABLE 4-2. EFFECT OF WINDOWS ON HEAT LOSS

Axel R. Carlson

HOUSE, 24-0X48-0, 1-STORY, DAYLITE BASEMENT

ALTERNATES: FIRST FLOOR	(Window) R-VALUE	3-2 pct AREA ft*2	3-2 pct LOSS Btu/ HR-F	6-4 pct AREA ft*2	6-4 pct LOSS Btu/ hr-F	9-6 Pct AREA ft*2	9-6 Pct LOSS Btu/ hr-F	12-8 Pct AREA ft*2	12-8 Pct LOSS Btu/ hr-F	15-10 pc AREA ft*2	15-10 pc LOSS Btu/ hr-F
WALL 2X4 3.5 FG 8 OC	10.83	1,054	97.3	997	92.1	939	86.7	882	81.4	824	76.1
			331.2		357.0		383.1		408.8		434.4
WALL 3-SQ 6"	9.30	1,054	113.3	997	107.2	939	101.0	882	94.8	824	88.6
			347.2		372.1		397.4		422.2		447.0
WALL LOG MILLED 9"	12.21	1,054	86.3	997	81.7	939	76.9	882	72.2	824	67.5
TOTAL			320.2		346.6		373.3		399.6		425.8
WALL LOG TURNED 12"	13.58	1,054	77.6	997	73.4	939	69.1	882	64.9	824	60.7
TOTAL			311.5		338.3		365.5		392.3		419.0
WALL LOG TURNED 14"	15.93	1,054	66.2	997	62.6	939	58.9	882	55.4	824	51.7
TOTAL			300.1		327.5		355.3		382.7		410.1
WALL 2X6 5.5 FG 8" 0	17.45	1,054	60.4	997	57.1	939	53.8	882	50.5	824	47.2
TOTAL			294.3		322.0		350.2		377.9		405.6
CEILING 16.5 FG	58.23	1,187	20.4	1,187	20.4	1,187	20.4	1,187	20.4	1,187	20.4
TOTAL			320.4		346.2		372.2		398.0		423.6

B:HET-LOG2.CAL, A1:L64, 09-01-83, REV 9/26/83

Professor Emeritus, Co-operative Extension Service, University of Alaska, Fairbanks, Ak.99701

TABLE 5. AVERAGE THERMAL VALUE OF WALLS

Axel R. Carlson

TYPE SECTION	WEIGHT		THICKNESS		INSULATION VALUE			SPECIFIC HEAT	
	ENGLISH	METRIC	ENGLISH	METRIC	ENGLISH		METRIC	ENGLISH	METRIC
	lb/ ft•2	kg/ m•2	Avg in	Avg cm	Btu/hr- in-ft•2-F	R-value	W/ m•2-C	Btu/ ft•2-F	W/ m•2-C
Log 3-SQ 6"	15.3	74.7	6.00	15.24	.1075	9.30	52.77	20.29	115.12
Log milled 8"	16.4	80.2	6.44	16.36	.1002	9.98	56.64	21.78	123.57
Log 3-SQ 8"	17.0	83.2	6.68	16.97	.0966	10.35	58.75	22.59	128.17
Stud 2X4 solid wood	16.5	80.7	4.00	10.16	.1429	7.00	39.72	6.17	35.01
Stud 2X4 3-1/2" FG 8" OC	10.4	50.9	4.00	10.16	.1300	7.69	43.64	2.77	15.72
Stud 2X4 3-1/2" FG 10" OC	10.1	49.5	4.00	10.16	.0877	11.40	64.69	2.61	14.81
Stud 2X4 3-1/2" FG 12" OC	10.0	48.6	4.00	10.16	.0858	11.66	66.16	2.50	14.19
Stud 2X4 3-1/2" FG 16" OC	9.7	47.5	4.00	10.16	.0845	11.84	67.19	2.37	13.45
Stud 2X4 3-1/2" FG 24" OC	9.5	46.3	4.00	10.16	.0828	12.08	68.55	2.24	12.71
Log milled 9"	19.1	93.4	7.88	20.02	.0812	12.32	69.91	25.36	143.90
Log tapered 12"	23.6	115.3	8.76	22.25	.0736	13.58	77.05	31.33	177.76
Log tapered 14"	30.0	146.5	10.28	26.11	.0628	15.93	90.42	39.78	225.73
Log tapered 16"	34.3	167.2	11.88	30.18	.0543	18.41	104.49	45.42	257.71
Stud 2x6 solid wood	21.5	105.1	6.00	15.24	.0927	10.79	61.23	8.71	49.42
Stud 2X6 6" FG 8" OC	11.9	58.3	6.00	15.24	.0573	17.45	99.02	3.36	19.07
Stud 2X6 6" FG 10" OC	11.5	56.1	6.00	15.24	.0557	17.96	101.92	3.11	17.65
Stud 2X6 6" FG 12" OC	11.2	54.7	6.00	15.24	.0546	18.32	103.95	2.00	11.35
Stud 2X6 6" FG 16" OC	10.8	52.9	6.00	15.24	.0532	18.79	106.61	2.95	16.74
Stud 2X6 6" FG 24" OC	10.5	51.1	6.00	15.24	.0519	19.28	109.40	2.74	15.55
Concrete 6"	75.0	366.2	6.00	15.24	.5025	1.99	11.29	99.45	564.33
Block 8X8X16	56.6	276.5	7.50	19.05	.4545	2.20	12.48	75.08	426.07

DESIGN FACTORS:

Wood at 15 % MC, R-val	1.550
Wood Btu/lb-F	1.326

CONVERSION FACTOR:

Btu/ ft•2-F	X	5.6745=	W/ m•2-C
lb/ ft•2	X	4.8824=	kg/ m•2

B:WAL-THER.CAL, Al-K45, 09-06-83, REVISED 9/26/83

Professor Emeritus, Co-operative Extension Service, University of Alaska, Fairbanks, Ak. 99701

FEASIBILITY OF LARGE LOG BUILDINGS FOR THE MACKENZIE VALLEY: AN INTERDISCIPLINARY STUDY WITH THE GOVERNMENT OF THE N.W.T.

BY
TANG LEE
FACULTY OF ENVIRONMENTAL DESIGN
THE UNIVERSITY OF CALGARY
CALGARY, ALBERTA

1. INTRODUCTION

Few building materials are as simple and basic as log from a tree trunk. In any civilization where there is an abundance of trees, log will almost always be used for building shelters. The physical properties of wood are easily grasped, and through centuries of experience, its behaviour is well understood. Compared to other indigneous materials, logs can be easily harvested and, it has good structural and insulative properties. It is a seemingly ideal material to use, especially in remote places where the transporting of other building materials is a major expense.

The problem with using logs for the far north is that the severity of the climate imposes undue hardships on the material. For examples, the extreme cold temperatures burden the logs with greater heat and vapour flows which it must try to resist. Before using this material, it is only prudent that we ask how well would a log wall perform under such conditions.

The Department of Public Works, Government of the Northwest Territories wished to learn more about using log structures for some of their buildings. A proposed school and community hall in Snowdrift was used as a model for testing the feasibility of this concept. Mr. Harold Strub, project manager, Project Management, Architectural Division of DPW was to lead the study. A team of participating specialist from private industry, ranging in expertise from forestry to building science (see Section 6) provided detailed input to the study. In addition, over 40 people from across Canada and the United States, including native groups, had also been consulted. The result of the effort is a technical report (1) and a set of recommendations to the Government of the N.W.T.

This paper will summarize the results of the building science investigation. The contents are those of the author and may not reflect the views of DPW or other members of the study team.

2. BUILDING SCIENCE ANALYSIS

2.1 Method of Assembly

The most common method of constructing a log wall consists of scribe-fit logs lapped at corners or stub wall junctions. As roof loads rests directly onto the horizontal logs, the roof settles whenever the logs shrink. DPW identified the piece-on-piece method as the most appropriate for this project. The piece-on-piece method involves horizontal logs slotted to vertical posts. Roof loads are carried by the log beams on top of the posts, similar to the post and beam method of conventional framing. The area between the posts can be filled with any material, the most common being horizontal filler logs. The ends of the horizontal infill logs are carved to slot into the vertical posts. Four examples of the filler logs joining the vertical posts are seen in Figure 1 below.

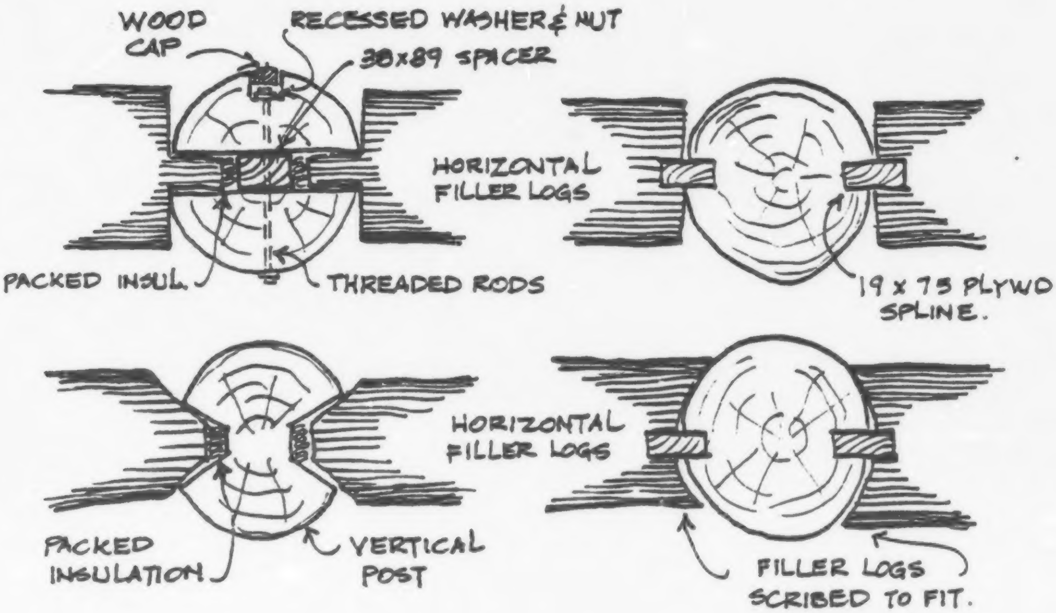

WOOD CAP
RECESSED WASHER & NUT
38x89 SPACER
HORIZONTAL FILLER LOGS
PACKED INSUL.
THREADED RODS
19 x 75 PLYWD SPLINE.
HORIZONTAL FILLER LOGS
PACKED INSULATION
VERTICAL POST
FILLER LOGS SCRIBED TO FIT.

Fig. 1: Details of Filler Logs Joining Vertical Studs in Piece-on-piece Style.

The advantages of the piece-on-piece style are fairly convincing for this project. Since there is very little vertical shrinkage parallel to its grain, the height of the posts will not decrease. As a result, differential roof settlement is minimized thus maintaining overall stability and furthermore stresses on windows and doors will be avoided. Another advantage is that shorter logs which would not be feasible to use on other log styles, can be used as infill logs. Furthermore, the spacing between the vertical posts can be varied to suit the lengths of available logs.

An important advantage of the piece-on-piece method is its modular nature. Off-site fabrication which allows separate teams to work on different panels and at different speeds may be an important feature on this project. Whereas traditional log walls are built one log at a time, the piece-on-piece method need not follow such progression. This feature may be important where the labour force may have varying log building experience.

Another advantage of the piece-on-piece method is its inherent design flexibility. Odd corners is easily accomodated by merely grooving the vertical posts at the appropriate angle. As mentioned above, spacing between the posts can vary depending on the length of available logs, the necessary span, and the desired spacing. As with post-and-beam construction, future additions and alterations are possible without modifying the superstructure. For asethetic reasons, the vertical posts can even be emphasized by using larger posts.

2.2 Seasoning

Logs should be properly seasoned before use to minimize shrinkage, cracking and undue stresses. Natural air drying of green log after debarking is better and more sensible for this location. Moisture content in the logs should be below the fibre saturation point. The cold dry climate of the far north will likely reduce the moisture content further.

A reasonable time between log harvesting and construction is approximately one year. The potential logs around the Snowdrift area are not the best specimen for construction purposes. A stockpile of good quality logs at Fort Resolution, approximately 200 km towards the southwest, may be used for this project.

2.3 Thermal Analysis

The design thermal resistance value for wood is minimal when compared to insulating materials. The National Research Council's Division of Building Research considers the insulating value of wood to be between an insulating and conducting material.(2) If a material has less insulating value than wood, it is considered a conductor of heat. Similarly, if a material has more insulating value than wood, it is considered an insulator. ASHRAE (3) and CGSB (4) assigns an RSI of 0.22 W/(m².K) and 0.23 W/(m².K) respectively to wood.

Traditional design values for thermal resistance of a material are based on tests conducted at room temperatures of approximately 20°C. Yet these values are used in calculating heat flows through a material regardless of the temperatures it encounters. For example, the design thermal resistance of rigid insulation is 0.036 W/(m².K), but when subjected to temperature of -10°C, the RSI increase to 0.032 W/(m².K). The calculations based on traditional design value will over estimate the amount of heat loss through this insulation. ASHRAE gave some recognition to this phenomena by listing the varying thermal conductivities of over 50 building materials at various temperatures.

Preliminary tests by the Eastern Forest Products Laboratories (EFPL) found wood increases in thermal resistance as temperatures decrease.(5) When wood is subjected to -10°C on one side and 20°C on the other, its RSI averaged 0.32 W/(M².K), which is a 39% improvement. A chart derived from the EFPL interim report is reproduced in Figure 2 showing increasing thermal resistance for wood as mean temperatures decrease.

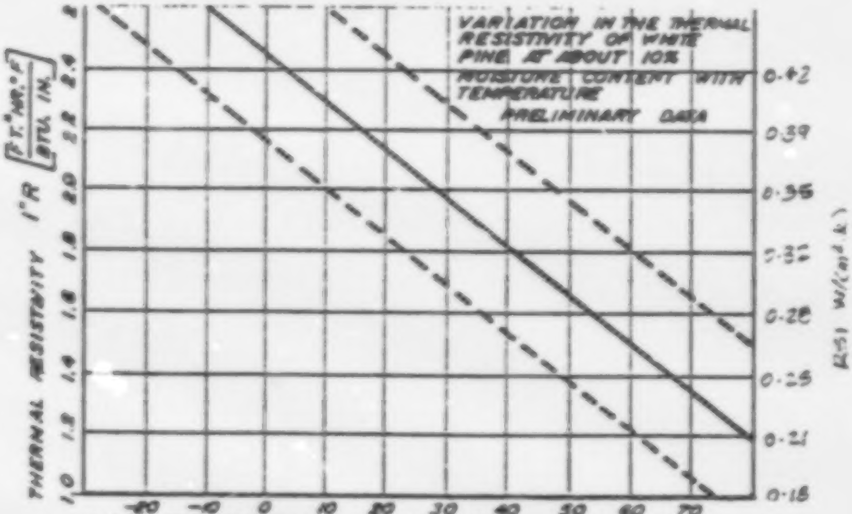


Fig. 2: Variation in the Thermal Resistance of White Pine.

2.4 Thermal Mass Effects on Heat Loss

Heat loss calculations are almost always based on steady-state conductivity values of building materials. Under fluctuating temperatures such as those commonly expected around a building, the thermal dynamic properties of the enclosure will respond differently. The calculated heat loss through the enclosure based on steady-state values will differ from the measured heat loss.

Proponents of heavy building materials such as the masonry and concrete industries, have always argued for changes in the heat loss design procedures to account for the dynamic behaviour of such materials under fluctuating temperatures. A test conducted by the Portland Cement Association (6) to compare the heat loss values of a number of walls, demonstrated heavier walls perform better than the calculated values. The walls had been tested in a calibrated hot box, and subjected to simulated outdoor fluctuating temperatures.

Allard and Troxell (7) found solid wood wall averaged 12.5% to 20.9% better than heat flow calculated using steady-state method. Their simulation model however, includes the warming effects of solar radiation (sol-air effect) which raised the outside surface temperature to 45°C.

Finally, a side by side thermal performance test using six unoccupied buildings, each with a different wall assembly, is being conducted in Gaithersburg, Maryland, by the National Bureau of Standards.(8) Preliminary results indicate the log building having a RSI of 1.8 W/(m^2.K) is performing as well as the insulated wood frame building having a RSI value of 2.1 W/(m^2.K) during the winter season. More remarkable differences occured during the intermediate heating season when the log wall consumed less than half the fuel of the wood frame building.(9)

A relationship between changing conductivity with changing temperatures between -50°C and +100°C can be expressed as

$$k2 = k1\ [1 - (1.1 - 0.98 \times S2)\ \frac{T1 - T2}{100}] \qquad (1)$$

where $k2$ = thermal conductivity at temperature T2, $W/(m^2.K)$
$k1$ = thermal conductivity at temperature T1, $W/(m^2.K)$
$S2$ = specific gravity based on oven dry weight and volume.

and the thermal resistance can be calculated given

$$RSI = \frac{L}{K} \qquad (2)$$

where RSI = thermal resistance, $W/(M^2.K)$
L = thickness of material, mm
K = $k2 \times$ area.

One of the study team member, Dana Ferguson, visited the Fort Resolution School and Community Centre on February 12, 1983. He measured the temperatures on both sides of the log wall on this building to determine the rate of heat loss. The actual thermal resistance in imperial units can then be determined with the following

$$R = \frac{0.94\ (ti - to)^{0.96}}{(ts - ti)^{1.08}} \qquad (3)$$

where R = thermal resistance, $Btu/(hr.ft^2.°F)$
ti = inside wall surface temperature, °F
to = outside wall surface temperature, °F
ts = inside air temperature 1 ft. from wall, °F.

With an oudoor air temperature of approximately 3°F (-16°C), the average thermal resistance of the log wall is 1.62 $Btu(hr.ft^2.°F)$ or 0.29 $W/(M^2.°C)$.

2.5 Moisture Content

The basic technical information on the effect of water on thermal conductivity is provided by J.S. Crammerer.(10) He assembled information world wide to show that thermal conductivity of all construction materials will rise as moisture is absorbed. Water and moisture affect thermal conductivity because it replaces the air (or other gas) in the cells of foams or between fibres in fibrous materials. Even fairly thin films of water within a material will increase its thermal conductivity. When all of the air in the material is replaced with water, the thermal conductivity of the material will approach that of water.

Bomberg and Shirtliffe (11) tested the thermal conductivities of concrete and fibreboards under various equilibrium moisture content. In one of the samples tested, the thermal conductivities measured 0.2 W/(m².K) and 0.4 W/(m².K) for moisture content of zero and 100 kg/m3.

Like other materials, moisture content in wood is directly affected by the relative humidity of the surrounding air. Figure 3 shows the relationship of equilibrium moisture content in most common woods and relative humidity.(12)

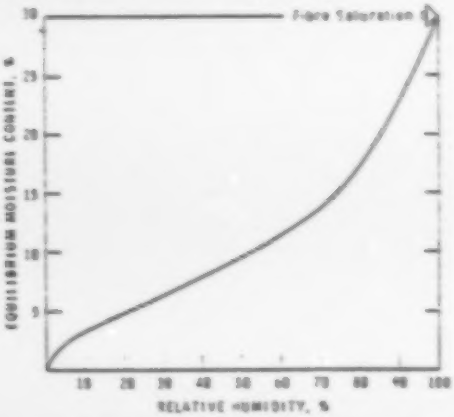


Fig. 3: Moisture Content of Wood at Various Humidities.

Using laboratory and field data representative of Canadian conditions, Max Baker at NRC has been able to draw some general guidelines about moisture content to be expected in particular environments.(13) Figure 4 below is reproduced to show the moisture content variations for wood indoors and outdoors for both winter and summer conditions. The figure may not be representative of log walls since there are many other variables affecting the rate and retention of moisture in a log wall. Nevertheless it does show one more dynamic variable to be considered in trying to fully understand the nature of log behaviour.

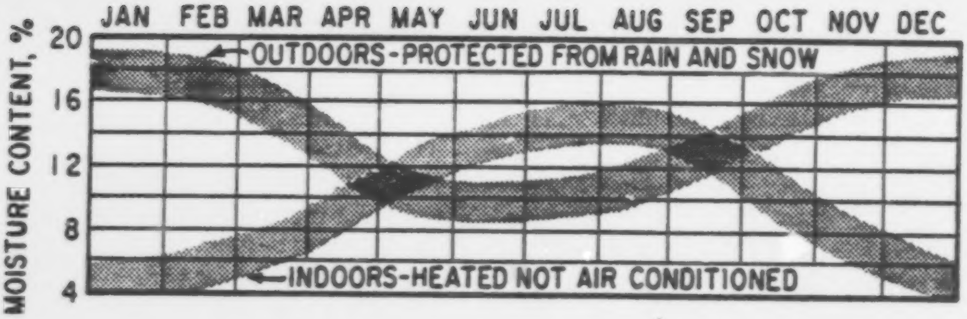


Fig. 4: Moisture Content of Wood in Use.

To confirm the readings in the above figure, moisture content readings was taken ot the Fort Resolution Community Hall. The average indoor relative humidity was 22% on February 12, 1983. Readings taken 5 mm into the logs from the inside wall averaged 8%. This correlated well with Bakers' graph. Such low moisture content would certainly increase the thermal resistance property of the log wall. Readings taken from the outer surface however, averaged 20%.

2.6 Air Leakage

The inevitable shrinkage, differential movement and settlement in log structures will cause separation between logs. Due to seasonal moisture changes with the logs expanding on one side while shrinking on the other, the walls may not change in height. The joints between the logs however, will open on the inside while closing on the the other side from summer to winter, with reverse action taking place from winter to summer.(14) Unless the joints are filled with a durable non-porous, expandable material, air leakage will occur in a log wall. For optimum energy efficiency, the log wall must be fairly air tight to reduce exfiltration heat loss.

Due to the extreme cold of the far north, moist interior air exfiltrating through cracks in the wall will condense and freeze within the wall. This condition has the advantage of sealing the cracks with ice. Sherwood (15), in his account of early building techniques found the practise of putting clay slurry on the building after freezing weather helped to seal the cracks. Apparently when the wet clay freezes, it expands to form an almost air tight seal.

Historically, caulking of oakum, clay, and batten and mortar were employed to seal between logs. Today, glass fibre insulation is more commonly used. Due to glass fibres' porous nature, it is not an effective air seal. Obviously if the glass fibre is totally compressed, it will be air tight. However, the purpose of having a gasketing material between the logs is to maintain an air seal under differential movements in the joints. Any movement which renders the glass fibres less than totally compressed will not stop air leakage, but merely filter the air passing through. One of the study team members, Jeff Rounds, had some success with the "air-core" type batt insulation designed for use in freezer.

This study examined other joint gasketing material for use between logs to minimize air leakages. One gasketing material having some promise is a polyethylene foam sheet called "Ethafoam 221".(16) This material is already replacing glass fibre insulation as a sill gasket between top of foundation and the sill plate in many buildings. The material has even been recognized by some local building authorities.(17) The standard size is 6 mm x 90 mm x 120 mm (1/4" x 3-1/2" x 5-1/2") wide rolls. Since joints between logs have less dimensional tolerances, and logs experience considerable more movement than concrete foundation and milled wood plates, a thicker gasket should be used. Some of the significant advantages of the Ethafoam 221 is its high water resistance and good thermal resistance.

Another product worth considering as a gasketing material for between logs is called the "HBR Backer Rod".(18) This is a closed cell polyethylene foam rod which is often used in conjunction with a sealant to form an air tight barrier. This material may be particularly useful for sealing around doors and windows. When using the backer rods, specify a diameter which is 30% larger than the joint width since the material will creep up to 25% of its dimension. Interestingly enough, Dow Chemical also makes a similar, if not identical backer rod called "Ethofoam SB".

At Fort Resolution, Mr. Ferguson conducted a carbon dioxide test to determine the infiltration rate of the School as a check against theoretical calculations and actual heat loss values. The tracer gas test gave an equivalent "infiltration" rate of 0.42 air changes per hour. The calculated air change was almost 70% higher at 0.71 air changes per hour. The discrepancy may have resulted from partial isolation of the crawl space to the even disbursement of the tracer gas. Nevertheless the test indicated the air leakage rates in the Fort Resolution School to be less than commonly believed. Obviously more measurements are needed from log structures before any generalizations can be made.

2.7 Vapour Diffusion

Vapour diffusion in air is a gas which exerts its own vapour pressure, and which can move into and through materials under differences in its own vapour pressure independently of the air with which it is mixed. Water vapour transmission through materials under the influence of a water vapour pressure gradient is called vapour diffusion.

The principles by which water vapour migrates through the building enclosure, and its damaging effects are well known. Methods to calculate the vapour diffusion through a building enclosure for the purpose of determining potential condensation problems are fairly simple.(19)

The Alberta Building Code, 1981, article 9.26.3.4 requires vapour barriers to confrom to CAN2-51-33-M77, "Vapour Sheets for Use in Above-Grade Building Construction." In article 9.26.5.2, vapour barriers need not be used if plastic insulation has a permeance rating of not more than 6 ng/(Pa.s.m^2). The permeance rating of a few selected materials are listed in Table 1 below for comparison purposes.

Table 2: Permeance Rating of Selected Building Materials.

MATERIAL	THICKNESS mm	PERMEANCE ng/(Pa.s.m^2)
Polyethylene	0.05	9.19
	0.10	4.60
	0.15	3.45
	0.20	2.30
Gypsum Board	12.5	2870 - 8100
Wood	25.4	23 - 310
Douglas fir plywd (ext.)	6.4	40
(int.)	6.4	109
(ext.)	12.7	55

The large variance in the permeance rating for wood depends on the direction of vapour flow. The higher vapour flow is obviously parallel to the grains. If we assign a permeance of 40 ng/(Pa.s.m^2) to wood, it will require 160 mm of wood to achieve the required vapour resistance. For a vapour barrier to be effective, however it must be placed on the warmer side of the dewpoint temperature.

Similar to combining thermal resistances to achieve a total performance, vapour resistance can be increased by combining a number of materials. Special paints are on the market with higher vapour retardant characteristics than ordinary paints. Log walls can be coated with these paints to achieve the required vapour resistance. If asethetics is a concern, certain types of stains and other coatings can be used. Axel R. Carlson from the University of Alaska advocates coating the inside of logs with a clear urethane or epoxy coating to minimize shrinking, warping, twisting and rotting.(20) He also mentions the importance of sealing the joints and other wall penetrations to achieve total protection.

2.8 Fire Hazards

The aim of the fire codes is not to fireproof a building but to establish the standard for fire prevention, fire fighting, and life safety in buildings in use including standards such as fire detection and egress facilities. The ultimate aim of fire safety is to safely remove the occupants away from the burning building. In the far north however, going outside to -30°C temperatures without proper attire can be as hazardous as the burning building.(21) Standing outside and possibly being wet from the melted snow and fire fighting activities, will quickly render the person very cold. The person must be quickly dried and taken to another building before the onset of hypothermia.

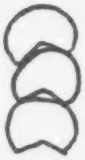
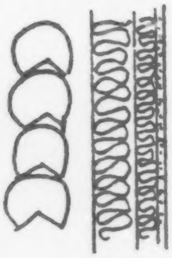
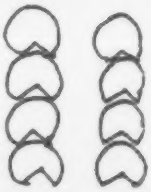
It is well known that fire fighting systems today include control of smoke, a by-product of combustion. While smoke from buring wood is hazardous, it is less so than other materials, especially petroleum based products. Depending on the type of furnishings, the log building will generally produce less toxic smoke during a fire than a wood frame building with rigid insulation, vapour barriers, and painted walls.

Although untreated wood will indeed burn, the natural insulative properties of wood will maintain the structural integrity of the structure longer than a steel building exposed to the same fire condition. Where extra fire safety is desirable, the surface burning characteristics can be reduced considerably by impregnating the wood with a suitable fire retardant chemical. We recomended the use of fire retardants in this project and have included the extra premium in our building estimates.

3. SUMMARY OF WALL PROFILES

A number of wall assemblies, from single wythe log wall to composite walls have been examined by the study team. Table 2 below summarizes the results of our analysis.

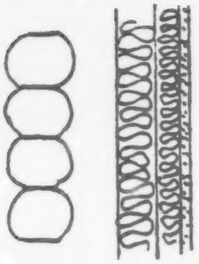
Table 2: Merits of Wall Assemblies Analysed.

WALL TYPE (RSI)	COMPONENTS	COST \$/M^2
"A" (3.0) 	250 mm log External finish coat Internal fire retardant MERITS: Simple to construct, Fairly economical A true log wall DISADVANTAGES: Low thermal resistance Potential air leakage	\$330.00
"B" 	250 mm log External finish coat 15# building paper 150 x 150 timber studs @ 300 mm o/c 150 mm batts vapour barrier 50 x 75 mm wood strapping 75 mm batts 12 mm drywall paint MERITS: High insulation value Good air/vapour barrier detail DISADVANTAGES: Complicated More expensive Fragile drywall Logs not seen on inside	\$351.00
"C" 	250 mm logs External finish coat Internal fire retardant internal fire retardant 250 mm logs Internal fire retardant	\$670.00

MERITS: Better insulation than "A"
Logs seen on both sides

DISADVANTAGES: Building two log wall
Minimal insulation gain
Very expensive

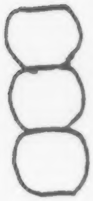
"H" 250 mm milled logs $287.00
External finsih coat
15# building paper
150 x 150 timber studs @ 300 mm o/c
150 mm batts
Vapour barrier
50 x 75 mm wood strapping
75 mm batts
12 mm drywall
paint



MERITS: High insulation value
Good air/vapour detail
Fairly economical

DISADVANTAGES: Logs not seen on inside
Fragile drywall
More complicated to build

"J" 250 mm milled logs $230.00
External finish coat
Internal fire retardant



MERITS: Most economical
Least labour
simple to build
Better joint seal detail

DISADVANTAGES: Low insulation value
Some air leakage potential

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4. Sociological Benefits

The social benefits of log construction are not normally discussed in a technical paper such as this. However, there are some convincing social arguments for the use of logs in this project which should at least be mentioned here. The advantages of using logs for the Snowdrift School and Community Hall are as follows:

- Log construction is the community's choice and will thus be better appreciated.

- It maximizes community participation in the project,
- Estimated wages left in the community as a result of hiring local personnel amounts to between $200,000 to $315,000, and,
- Potential for the establishment of a local industry with a skilled labour force.

5. CONCLUSION

It can be argued that the single wythe log wall (Type "A") is inappropriate for use in the far north because it lacked sufficient insulating value. It can also be argued that log structures are inappropriate for anyplace where there is a heating load . In this project however, the thermal performance of the wall must be considered in relationship with other parts of the building enclosure such as the roof, floor and windows. In a large project such as proposed for Snowdrift, the total gross floor area is 1300 m^2. The ratio of enclosure area and volume contained is certainly less than for a single family dwelling of 120 m^2. In this project, the outside wall area of a one storey building is 290 m^2 or representing only 15% of the total enclosure surface area. A thermally weak wall can easily be made up by increasing slightly the insulation values of the other surface areas. In addition, the design of the building can minimize the heat loss through the walls by creating intermediate temperature zones such as vestibutes, corridors, and storage rooms.

The decision to use log construction for the walls of the Snowdrift School and Community Hall is less dependent on its thermal properties, but on other matters such as the sociological aspects discussed in this paper.

6. LIST OF PARTICIPATING SPECIALISTS

Cost Consultants: Iain Barnett	Barnett, Treharne, Yates Inc. Winnipeg, Manitoba.
Mechanical Engineering: Computer Simulation: Dana Ferguson	Ferguson, Simek & Clark Ltd. Yellowknife, N.W.T.
Forestry Expertise: Al Grimmer	Grim-Tek Services Limited. Edmonton, Alberta.
Building Science: Tang Lee	Tang G. Lee Architect Ltd. Calgary, Alberta.
Log Construction Technique: Allan Mackie	B. Allan Mackie School of Log Building Prince George, B.C.
Structural Engineering: Norman Read	Yellowhead Engineering & Technical Services Ltd. Smithers, B.C.
Log Building Design: Jeff Rounds	Killick, Metz, Bowen, Rose Architects Whitehorse, Yukon.
Coordination/Compilation: Harold Strub (403) 873-7818	Architecture Division Department of Public Works Government of the N.W.T. Yellowknife, N.W.T. X1A 2L9

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1" dia. x 650 ft. ... $73.00

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RURAL RESIDENTIAL ENERGY CONSERVATION

THE NORTH SLOPE BOROUGH EXPERIENCE IN ALASKA

BY
Johnny Adams and Jerry Cogdill
North Slope Borough Utility Department
P. O. Box 69
Barrow, Alaska 99723

AND

Earl Finkler
Director of Planning, CSM
3900 Arctic, Suite 301
Anchorage, Alaska 99503

The North Slope Borough in Arctic Alaska is a key area for energy planning and conservation. The Borough stretches over 88,000 square miles and its 5,000 permanent residents in eight villages pay some of the highest energy costs in the nation. Fuel oil can run $3.00/gallon or higher, and it costs the Borough Utility Department almost $1/KWH to generate electricity.

Energy is a critical factor in the future economy and survival of the Borough's people and their villages. The oil-related economic boom and the subsequent Borough Capital Improvements Program have resulted in many new houses and buildings in each village. Electrical demand has been growing by about 30 percent per year in Barrow, the largest NSB community, and heating demand by 20 percent between 1981 and 1982.

The Borough has provided many high-paying temporary construction jobs. However, when the boom slows, or stops, the wages will go down or disappear, but the buildings and high energy costs will remain. One recent state-wide study by the Institute of Social and Economic Research predicted that in rural Alaska the proportion of Native household cash spent on energy will rise from 29% to 43% by 1988. On the North Slope, this could mean that people will be spending almost half of their available cash on heating and electricity unless something is done. The Borough Utility Department has been anticipating such problems for some time. It has aleady instituted a progressive electricity rate structure where higher users pay more per kwh than those who use less. The rate structure includes a lifeline base of 600 kwh.

The Borough's approach to the problem is headed by the Mayor's office and the Assembly, but it features cooperation among various line departments such as Utilities, Housing, and Public Works. In 1981, the Assembly's passage of 12 basic energy policies got the program started on a solid foundation. Subsequent Assembly, Mayoral, departmental, village, and resident participation have carried out coordinated actions with increasing momentum.

Key components of the Borough's energy program include the following:

1. An Overall Emphasis on Conservation
The Borough views conservation as an important traditional and cost-effective source of energy. In pilot residential energy conservation programs carried out in three of the eight villages to date, we estimate 10-year savings of over $880,000.

2. Extensive local hire and participation.

Johnny Adams, one of the three people presenting this paper, is an Inupiat energy planner who has been with the Borough energy program since its inception. Earl Finkler trained Johnny in energy planning, and Johnny helped train Earl and other non-Natives in many aspects of traditional energy conservation, including details of the sod house concept which will be presented later. Jerry Cogdill has continued to coordinate day-to-day Utility Department operations and fuel matters with Johnny's energy office.

In addition, the Borough energy conservation program relies on the extensive use of local labor to install energy conservation items and improvements in local homes under the supervision of an outside energy retrofit expert. To date, in the three villages with completed home energy conservation projects, about one-fourth of the total budget has been paid out in local hire wages.

3. Emphasis on residential conservation

The Borough has already incorporated some energy conservation practices on a larger scale (such as waste heat recovery systems), but there is a strong emphasis on weatherizing individual residences. It is important in the Borough to work with each household on an individual basis—for both demonstration and educational purposes.

In a typical case in our program, an auditor team would visit the house, introduce the program to the residents, take measurements, and discuss preliminary findings. This is followed by a return visit to present their completed forms and discuss retrofit options.

However, our Borough village programs have fared better than many other rural and urban programs in Alaska because of the extra steps we have taken, including the following:

A. Basic information was given out [illegible] preliminary general public meetings.

B. Johnny Adams provided important se[illegible]s with Inupiat translations, interviews of residents on traditional [illegible]ergy use, and follow-up with individual homeowners to help ensure understanding of the program and to deal with any minor problems.

C. The auditors relied heavily on concrete demonstrations of energy conservation materials at the start of the home visit to help explain the program. Energy saving devices were demonstrated at public meetings and samples were passed out. Fluorescent screw-in bulbs were installed in table lamps and light fixtures. Outlet gaskets were also installed on exterior walls and residents were invited to feel the reduction in drafts. These early demonstrations of retrofit techniques were much more helpful in explaining the program than all the paperwork and brochures.

The Borough's philosophy of priority residential coverage has been emphasized by the former Borough-wide Utility Board, and continued by the Mayor and the Assembly, as well as the Utility Department. Lower cost energy sources are expected to be investigated and developed where effective. For example, Utilities is recommending power line extensions from Barrow, which has natural gas, to outlying villages such as Atqasuk and Wainwright. Jerry Cogdill can also explain the Borough's progress in obtaining power cost assistance from the state. Non-residential conservation is also very important. But a solid start in both achievements and individual residential education has been made and will hopefully continue. Subsidies can help, but they are not guaranteed in the future. Conservation is a long-term investment.

4. Reliance on traditional energy conservation experience, including the sod house story.

The North Slope Borough is rather unique in energy planning experience since its residents have a long, proud tradition of energy conservation and energy self-sufficiency. Many residents of the Borough can remember heating their homes with coal, pitch, driftwood, seal oil and blubber, all locally available fuels. Energy-efficient sod houses are part of that tradition, along with the traditional consideration of environmental factors such as sun and wind in the design and siting of houses.

Johnny Adams has done extensive research on traditional energy use and can explain the concept in more detail.

5. Integration of State and Borough funding.

The Borough's residential energy conservation program to date has been funded in part through the standard state audit-retrofit program. However, the program was limited to a certain amount for each home audit and not more than $300 per unit for retrofit. The North Slope Borough stepped in and contributed enough funds to make the program viable in rural villages. To date the State has paid about one-fourth of the total project cost.

PROBLEMS AND RECOMMENDED SOLUTIONS

No pilot program can run very long without a few problems, especially in remote rural areas. Some of our problems included in the following:

1. The $300 State limit for conservation retrofit was too low for rural applications. The $300 figure was geared for urban areas in Alaska which have lower fuel, labor and material costs. It enabled the budget to be spread out among more urban voters, but it shortchanged rural areas.

2. Both the State and the Borough suspended their energy programs after we finished three of the eight villages under the pilot program. We are hopeful that the Borough will reschedule the remaining five villages in next year's capital budget.

3. The State energy audit program, although improved in the last year, was overly cumbersome and sometimes irrelevant or inaccurate. For example, standard infiltration calculations may not be accurate in the smaller, older houses which have high surface to volume ratios.

4. The State audit form infiltration calculations did not reflect the energy conservation problems associated with the rural lifestyle in a small Arctic village such as Anaktuvuk Pass (population about 225 people). Heat loss through infiltration can be accelerated by the rural Native lifestyle.

   The village home is a center of activity throughout the day, instead of only in the morning and evening, or on weekends. There is a lot of visiting and traffic in and out at all hours. Also, the standard correction factor used in energy consumption estimates to compensate for the heat from other sources than the furnace (i.e. cooking, lights and human activity) may be inaccurate. We question whether such sources can provide 30 percent of the heating in high Arctic communities.

5. The program did not include a monitoring component to measure actual before and after home energy conservation. All of our calculations are estimates and these do not gain as much political support as actual figures.

6. Ongoing maintenance of energy conservation improvements is a concern that has not been fully institutionalized. Storm windows must be rehung or screwed on after winter, and door and window weatherstripping need monitoring of wear and replacement. In addition, furnaces and heaters need annual checking and adjustment. We are coordinating with the Borough housing maintenance section for Borough-owned homes, but remain concerned about private homes. Our necessary emphasis on lower cost measures to reduce infiltration could be negated to a significant extent by a lack of ongoing monitoring and maintenance.

7. Traditional energy lessons are acknowledged to be important by Borough energy planners and consultants, but there is still no large-scale effort to integrate this knowledge into the design and retrofit of buildings and facilities. For example, in Anaktuvuk Pass we calculated that the one remaining sod house uses less fuel than any other house in the village. The house was well constructed to minimize infiltration and the below grade door provided a good cold trap and prevented warm air from escaping when the door was opened. The only retrofit necessary was a new custom insulated door, storm windows and some caulking around the window frame. Yet people desire modern western homes and many have been shipped to each village. What is needed is an all-out effort to incorporate energy-saving feathers from the sod house into the design of new houses and the retrofit of existing stock.

LESSONS FOR OTHER AREAS—RURAL ENERGY CONSERVATION PROGRAMS

1. An initial focus on residential conservation can be effective and can build energy awareness.

2. Pilot programs are fine, and a lot of improvements can be incorporated into subsequent phases. But future financial support cannot always be guaranteed.

3. One-shot programs are not enough. Ongoing monitoring and maintenance are essential.

4. Local people should be involved in all phases of the program — as energy planners, auditors and local hire retrofit crews. Participation should not be limited to public meetings.

5. Education and language are very important considerations. When working with Native people it is important to have staff who speak the language, and illustrations and materials which pertain to actual local conditions.

6. An ideal rural program mixes outside consultant knowledge of energy, systems, bureaucracy and paperwork with extensive local knowledge of traditional energy conservation, local lifestyles, weather conditions, fuel logistics and cultural preferences.

RETROFITTING GOVERNMENT BUILDINGS
IN
THE NORTHWEST TERRITORIES

BY

HARRIET BURDETT-MOULTON
ARCHITECTURAL PROJECT OFFICER
FROBISHER BAY, N.W.T.

ABSTRACT

The Canadian Eastern Arctic has problems that affect its construction industry. It is plagued with expensive transportation, expensive energy and a short building season. Often the most economically viable solution to the regional building plan is to retrofit existing buildings.

Projects for retrofitting are identified by an extensive building audit, a thermography scan and an evaluation of the energy consumption figures.

Exterior retrofits are the most effective way to rehabilitate a building for energy conservation. In remote communities fiberglass insulation and wood framing are the simplest means of construction. In more populous centres a sprayed urethane system has distinct advantages.

Retrofits in the Baffin Region have shown an economic payback of approximately 10 years and are saving 2/3 of the fuel cost.

RETROFITTING GOVERNMENT BUILDINGS

1. OVERVIEW

Historically and geographically construction in the Eastern Arctic has some inherent problems. There are no roads nor will there be in any forseeable future. There is no money for quick economic development so things happen as necessary on a restricted budget.

There are specific problems which result from:

1.1 Transportation

Everything comes to the Baffin Region by sea or air. Sealift (2 month season per year) brings in all major items at a cost of $196.00 a ton or $192.20 per 2.5M^3. ($7.14 per ft^3). For example one bag of R-20 fibreglass batt costs $25.00 to buy and $55.97 to ship to Frobisher Bay.

1.2 Cost of Energy

Oil is the basis for almost 100% of the energy in the Baffin Region. It is used for heating, transportation and electricity and ranges in price from 45¢/litre($2.05 imp. gal.) in Broughton Island to 57¢ litre ($2.59 imp. gal.) in Resolute Bay. The total energy cost to the Baffin Region was approximately 36 million dollars in 1980 or about $4,200 per capita.

1.3 Existing Buildings

Most of our buildings are old, by northern standards. Many in Frobisher Bay were inherited from the American Armed Forces (1950 edition). They are poorly insulated and may burn up to 96.81 litres per m² (1.98 imp. gal per sq. ft.) of fuel per year.

1.4 Construction Season

Climatically the building season is from May until October but sealift dictates a season from late July until December. This means construction under zero conditions which does not give the best product, ie. carpenters have to contend with frozen fingers as well as frozen caulking.

We have attempted to solve the sealift problem by ordering material one year and starting construction early the next season. This presents two problems:

a) A project has to be budgeted over two years and with Government there is no sure guarantee that the second years budget will be approved.

b) There is often not sufficient store housing in remote settlements to house bulk items for seven or eight months, and outdoor storage encourages vandalism and prey to the elements.

1.5 New Buildings

Based on the above facts one can assume new construction is expensive and correctly so. The residential cost this year ranged from $1,345. - $1,507. per m² ($125. - $140. per sq. ft.) in Frobisher Bay.

It naturally follows that if we have a lot of old buildings and new construction is very expensive, renovating or retrofitting may be a solution.

2. DETERMINING TARGET

The following methods are used in determining which buildings to renovate and which to let die a natural death:

1. Energy Audits
2. Thermography Scans
3. Consumption figures

2.1 Energy Audits

We have developed a simple version of energy audit forms to evaluate each house. This will indicate if the building is worth saving and also if any immediate maintenance is required.

2.2 Thermography Scans

This method will quickly point out major areas of heat loss. This is a photographic method of detecting heat loss by measuring the long wave radiation.

2.3 Consumption Figures

Checking the oil or electrical consumption per sq. meter of floor area for a building is one quick method of determining buildings that consume the most energy. The buildings in question should always be audited because high consumption may be due to life style or an unusual building quirk. For example, high electrical consumption often indicates excessive heat trace.

3. CONSTRUCTION METHODS

Two basic methods of retrofitting buildings have been used in the Eastern Arctic:

1. Exterior Retrofits
2. Interior Retrofits

3.1 Exterior Retrofits

For residents and multifunctional buildings, exterior retrofits are an effective method.

- tenants don't have to be rehoused (always a problem)

3.1 Exterior Retrofits

- everyday operations can continue to function
- it provides uncluttered working conditions for labourers
- a continuous vapour barrier can be installed

One drawback of this system is:
- the work is affected by adverse weather conditions

A major design consideration of exterior retrofits is the extra loading on the existing structure. It is advisable to consult a structural engineer.

3.2 Interior Retrofits

This method can only be used effectively on buildings such as warehouses where there are minimal internal partitions or none at all, to prevent a continuous vapour barrier. The advantage of this system is:

- construction can be done during mid winter

The major disadvantages are:

- building functions have to be rescheduled or tenants rehoused
- often a very cluttered work environment
- electrical and mechanical systems have to be upgraded

4. METHODS OF INSULATION AND INSTALLATION

There are three major methods of retrofitting that can be applied to the building's exterior or interior on wood or metal studs:

- Fibreglass batts
- Sprayed polyurethane
- Rigid insulation

4.1 Metal strapping should be avoided because of the thermal bridging. Wood strapping and fiberglass batts have been the most widely used because:

1. No special skills are required
2. Regular tools can be used
3. Temperature has very little effect on the materials

This method have the disadvantage of being:

1. Heavy
2. Labour intensive (lots of framing)

Wood and fiberglass batt lends itself well to remote communities where local labour is an asset.

4.2 Wood strapping and sprayed polyurethane is gaining popularity because:

1. It is cheaper to ship than fibreglass batt.
2. Less framing is required to achieve the same R-value.
3. It is less labour intensive.
4. The polyurethane system is lighter than the fibreglass system which is an advantage on older buildings.
5. It eliminates the need for a traditional vapour barrier because of its high resistance to the flow of moisture.
6. Insulates hard to reach areas and ducting spaces.

This system has three drawbacks that make it difficult to use in remote communities:

1. It requires skilled labour and specialized equipment.
2. Temperature restricts its use (ie. can't be sprayed when the temperature is too low).
3. Equipment transportation cost is high.
4. Fireproofing is required if used on the interior.

4.3 Wood or metal strapping and rigid styrofoam have been used in several applications. We have found it less than an ideal product because:

1. It is the most expensive of insulation for shipping.
2. There is a high rate of breakage in shipping.
3. There is a high thermal leakage (ie. never fitted tightly around the studs).

Rigid insulation acts better as a supplement to other insulations to reduce thermal bridging. A thin layer 3.8 cm (1 1/2") is often used as an exterior sheathing in new construction.

5. OPTIMUM R-VALUES

Optimum thermal resistance values can be claculated. Using this method new northern residential standards are being drafted which suggest R-values be varied depending upon the degree days.

18°C DEGREE DAYS PER YEAR

	6500	8000	9500	1100	12500
Minimum R.S.I.	5.61	6.22	6.78	7.30	7.78
R	32	35	38.5	41	44

For Frobisher Bay with 9931°C (17876°F) degree days R-40 is required in the walls, roofs and floors.

Degree days of some other well known points in the north are:

Whitehorse	6931°C	(12475°F)
Yellowknife	8686°C	(15634°F)
Rankin Inlet	10722°C	(19300°F)
Nome Alaska	7873°C	(14171°F)
Resolute Bay	12516°C	(22673°F)

6. MISCELLANEOUS

There are several items that are interdependent with a retrofit and may well determine the effectiveness of the finished product. The major items are:

1. Doors
2. Weatherstripping
3. Windows & Vent Boxes
4. Attic Vents
5. Levelling
6. Codes

6.1 Doors

Exterior doors present a problem in the north. Ideally they should be thermally insulated and placed on the warm side of an airlock entry. If metal insulated doors are on the cold side of an airlock and regular doors on the warm side (house side) there is a tremendous hoar-frost build up on the metal doors from air leaking through the regular doors. If two sets of well sealed metal doors are placed on the air lock, pressure builds up in the air lock such that one door is often left ajar.

The best solution to my knowledge has been to place weatherstripped insulated doors on the warm side of the air lock and unweatherstripped insulated doors on the cold side. This eliminates the build up of hoar-frost because the interior doors seal tighter.

6.2 Weatherstripping

This must be regarded as a maintenance item like regular painting to be replaced as required. It has been suggested that magnetic gaskets and surface mounted doors (similar to refrigerator doors) are a solution. This concept is good, but it is hard to achieve because no door manufacturers make the necessary frames and hardware to fit standard size doors and custom made finished work becomes financially prohibitive in remote communities. The best weatherstipping we have found for extreme cold is closed cell sponge neoprene flexible to -54°C (-65°F).

6.3 Windows & Vent Boxes

Regular operable windows freeze open in the winter causing tremendous heat loss. Two types of windows that have been very popular in the past have been the horizontal slider and the awning with a cogged lever to open or close it. Most horizontal sliders have the worst track record for heat loss in the north, because the vinyl spacers break with the cold leaving an open air passage to the outside and metal sliders have extensive thermal bridging. The opening mechanisms on awning windows often break because the window freezes open or shut and the extra pressure applied to correct this situation breaks the mechanism. A solution that could be considered in new buildings is fixed windows with heat exchangers.

6.3 Windows & Vent Boxes

Vent boxes have been used as an alternative to operable windows. This is one step better than an operable window because they don't lead directly to the outside. They are insulated and withstand more rough treatment than windows, but vent boxes are still a poor substitute for good windows because they have to be site constructed and cannot be made with the close tolerances required. If they were manufactured in a plant similar to a window this could be improved. It is extremely difficult to fit existing buildings with heat exchangers so we have to use vent boxes or operable windows. Three methods have been used, with some success:

1. Where vent boxes exist and the windows have recently been replaced with new triple glazing the existing vent boxes have been incorporated in the new wall system.
2. Factory made vent boxes have been used in existing walls where fixed triple glazed windows have been installed prior to a retrofit. The infiltration has been greatly reduced, but the asthetic value is definitely questionable.
3. Where new windows have been installed good quality windows with awning operning have been used. P.V.C. windows have given us the best performance. Their tested infiltration in a 40.23 km (25 mph) wind is as good as .0919 $\frac{m^3}{min}$ /m (.023 cfm/ft) and frost does not adhere to the P.V.C.

6.4 Attic Vents

Attic venting has provided jobs in the spring for many a D.P.W. maintenance man and there have been as many solutions as Regional Engineers. Attic vents have been provided in units to prevent moisture build up in attic spaces. In many cases they contribute to this problem by allowing powder snow to blow in. They do not do the job they were designed to do in the south because in the winter moisture vapour freezes on the underside of the roof deck before it is blown outdoors and often builds up to an impressive 10 cm (4") over the winter. When the spring sun melts the bond between roof deck and ice sheets they fall on the ceiling insulation and promptly melt, releasing buckets of water to the interior of the building.

In the Eastern Arctic the only buildings over 3 years old that do not leak in the spring are the ones with Cathedral ceilings, or buildings with the insulation on the external envelope and no ventilation. By adding a new insulated roofing system over the existing roof the insulation has been moved to the exterior of the building envelope with the old roofing membrane acting as a near perfect vapour barrier.

7. LEVELLING

Existing buildings almost without exception have moved. They should be levelled before exterior retrofitting starts; any skew in the existing building will be impossible to correct after the new skeleton has been put on. This often means installing new footings, upgrading the gravel pad and providing some means to prevent future erosion. Shallow, well insulated concrete or rock footings are ideal providing they do not intrude on the permafrost level. Reinforcing banks with wood ties or rock often ensures longer lasting gravel pads.

8. CODES

Recently the electrical code in the Northwest Territories have been interpreted to demand a total upgrading to meet present codes, if the service to a building has been disconnected and reconnected for the purpose of putting an exterior shell on the unit. This ruling has added an extra $5,000 per unit to the contract. This may change the economic feasibility of exterior retrofits. When the program was first started, the electrical system had to be upgraded only as far as the panel box, if no interior work was done. This appeared much more reasonable.

9. CONTRACT ADMINISTRATION

In the Eastern Arctic with so few Contractors and such heavy government influence the fine line of contract administration often becomes blurred. it is always best to have the contractor supply and install the materials for a project. However, if you wish to phase a project over two years this may not be possible. The Government may be in a position where it has to supply the materials one season and have a contractor install them the next. In this case each party's responsibilities must be clearly defined because if material is stolen, lost or broken, who pays for it? If equipment doesn't work properly, who is responsible - the supplier or the installer?

When Government uses its own forces for suppling and installing projects there is no control level. Cost control and time scheduling may often be overlooked if emergency situations arise. (ie. major breakdowns or freeze-ups may pull all Government workforces away from the job at hand). The best solution is to have a contractor supply material one year and install it the next. This method may cause the contractor such problems as:

- large overhead to carry for 1 year (We have eliminated this by payment of material when it arrives in the settlement)
- finding available storage space for a period of time
- confusion over responsiblity for material once it is paid for by the owner.

10. ECONOMIC PAYBACK FOR RETROFITS

BUILDING	TOTAL COST	THEORETICAL FUEL REDUCTION (Gals.)	ACTUAL FUEL REDUCTION (Gals.)	1ST YEAR SAVINGS	PAYBACK YEARS
Pangnirtung					
11-355	$ 42,728	803	519	$ 1,126	17
37-007	33,573	938	832	1,805	11
37-009	38,571	694	324	703	21
37-010	46,943	1808	2189	4,750	7
37-200	42,047	940	657	1,426	15
Frobisher Bay					
37-020	33,511	1209	1395	2,595	9
37-016	33,511	804	914	1,700	12
37-013	33,511	851	720	1,339	14
63-456	119,717	6512	6289	11,698	7
Total	424,112	14,559	13,839	27,142	10

NOTE: 1. An average annual oil cost increase of 20% and an 11% inflation has been assumed.

2. The decrease in maintenance costs have not been included.

10. PAYBACK

Retrofits can also be justified on the following basis:

a) It extends the functional life of the building.
b) It reduces the maintenance cost.
c) It improves the asthetic quality of the building.
d) It improves the internal comfort.
e) Increases tenanct satisfaction.
f) Increases resale value.

Many of the above items cannot be measured in terms of dollars. For example, anything that improves the quality of living in the Eastern Arctic and encourages people to stay longer and be happier is an asset. People are always the best natural resource.

11. SUMMARY

In summary I would like to emphasize the lack of alternate energy in the Eastern Territories. Therefore, energy conservation is the only thing we can use to reduce our dependency on oil. Retrofitting is a means of fuel conservation and a viable alternative to new construction which costs approximately $1,400. per m^2 ($130.00 per ft.^{2}) as compared to $495. per m^2 ($46.00 per ft^2) for retrofitting. The paybacks on our retrofits average 10 years which is less than 1/2 the expected life of the building. Approximately 2/3 of the fuel consumed by the building is saved (Figure #1).

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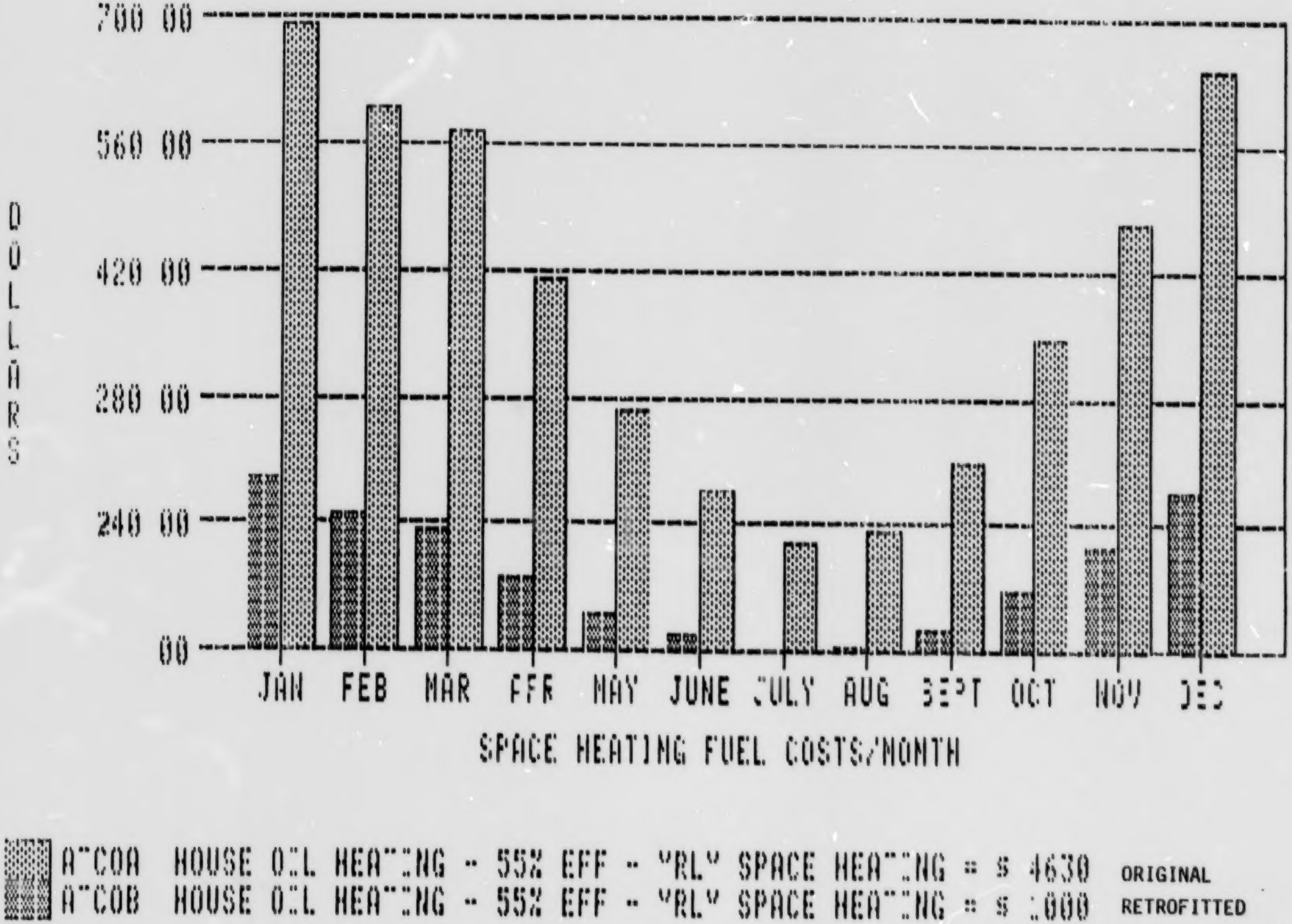
Figure #1


700 00
560 00
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DOLLARS
JAN
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AUG
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NOV
DEC
SPACE HEATING FUEL COSTS/MONTH
A"COA HOUSE OIL HEATING - 55% EFF - YRLY SPACE HEATING = $ 4630 ORIGINAL
A"COB HOUSE OIL HEATING - 55% EFF - YRLY SPACE HEATING = $ 1000 RETROFITTED

DISTRICT HEATING IN THE N.W.T. FOR DIESEL GENERATOR SUPPORTED COMMUNITIES

BY

DANA FERGUSON, P.ENG.
FERGUSON, SIMEK, CLARK LIMITED
YELLOWKNIFE, N.W.T.

Abstract

This presentation will review the evolution of district heating in the Northwest Territories for diesel generator supported communities and will discuss the design and administrative considerations associated with waste heat recovery in the Arctic. The paper presentation will also deal with a specific installation from concept through design, construction and operation.

1.0 INTRODUCTION TO THE EVOLUTION DISTRICT HEATING IN THE N.W.T. FOR DIESEL GENERATOR SUPPORTED COMMUNITIES

In the mid seventies, the Government of the Northwest Territories embarked on a program to maximize the energy use of non-renewable resources in the Arctic communities. As a result, they undertook a study of waste heat potential from existing diesel generating plants in the communities and in 1976, commissioned a pilot project in Cambridge Bay to evaluate that potential.

As a result of that pilot project, much was learned about the practicality of recovering waste heat in a community retro-fit application and in the administrative requirements to handle such projects between the Power Commission and the communities. Since that time, the Government of the Northwest Territories has been the leader in applying this retro-fit technology and has since commissioned systems in Rankin Inlet, further extensions to Cambridge Bay, Pelly Bay and Lac La Martre. Currently under consideration are additional projects in Fort Franklin, Coppermine and Pangnirtung.

The paper presented at this symposium represents in a very general way the real life design considerations for community retro-fit and a glimpse at several projects which are currently in operation. The emphasis is not to produce the detail engineering calculations used but to present the district heating and waste heat recovery retro-fit projects in their practical applications in remote communities.

2.0 DISTRIBUTION SYSTEMS FOR DISTRICT HEATING SYSTEMS BASED ON DIESEL GENERATOR WASTE HEAT.

2.1 OVERVIEW

Distribution systems begin at the outlet of the heat recovery devices and include the main distribution, lines, expansion tanks, valves, controls, pumps, makeup system, branch loops, terminal dissipation apparatus and fuel fired auxillary heat input equipment used as part of the system. Distribution systems can be classified as:

1) Water
2) Steam
3) Combination, Steam/Water

Design considerations for waste heat distribution systems are similar to those encountered in conventional district heating systems.

2.2 WATER SYSTEM

The distribution mains to the users from the generating plant can be a one or two pipe system as outlined schematically in Figure (7).

2.2.1 ONE PIPE SYSTEMS

One pipe systems will generally service more customers with less main piping for a typical community.

However, at a given supply temperature from the plant, higher flow rates (more pump horsepower and/or larger pipe) may be required to maintain acceptable primary temperatures for the customers further downstream. Additionally, the entire single loop must be sized for full design flow. A one pipe system requires that each branch connection be provided with a separate circulating pump. Because the supply water temperature drops in relation to the heat used by each consecutive customer serviced, single pipe systems are practically considered only for waste heat recovery supply temperatures of 95C and up.

In addition to technical considerations, the decision to use a one pipe system is financially based on the life cycle costs (capital cost plus operation and maintenance for the system life) versus that of a comparable two pipe system.

2.2.2 TWO PIPE SYSTEM

Two pipe systems have the advantage of a constant supply temperature (minus line heat loss) for each customer on the line. However, both the supply and return pipe must pass each branch service, usually resulting in more pipe being used compared to a single pipe system. Both the single and dual pipe arrangement require approximately the same amount of trenching and/or utilidor to service a given market.

Main pipe sizes are adjusted for the two pipe system based on the varying total flow requirements in the pipes after each branch customer take-off.

Pumping horsepower and/or main pipe sizes are generally less for two pipe systems than one pipe arrangements. Additionally, the two pipe arrangement does not require separate pumps for each branch service, although care must be exercised when considering the end-line customers as the systems are not usually reverse returned because of cost.

Two pipe systems are practical for waste heat supply temperatures as low as 65C, usually encountered on normal-temperature jacket water recovery.

2.2.3 COMBINATION WATER SYSTEMS

In many cases, the distribution arrangement which will provide the best life cycle cost will be a combination system using both one and two pipe sub-systems to service specific areas. The decision is based on customer density, customer heat requirements, terrain characteristics, easement arrangements, distance to the power plant, and capital available.

The preferred method for retro-fit energy recovery is solid water systems, as the modifications are usually within the existing engine operating parameters.

Sizing of the distribution piping is done in accordance with standard engineering practice for the fluid used, which may be water, or a water/glycol solution if a danger of freezing exists. Based on the line sizes, circulating pumps are chosen in relation to the heat transported and the maximum temperature drop acceptable to the customers.

An analysis should be carried out to define the requirement for peak load heating capacity or buffer heat storage tanks on the main system. Emergency backup heating in the event of distribution line failure should be maintained by the users. It is normal for the customer's original heating system to be incorporated as part of the retro-fit. Figures (8A) and (9A) show typical retro-fit applications for a forced air furnace and a boiler installation. Additional unit heaters and convector radiation may be added to existing systems where the waste heat supply water temperatures are below the original building design values.

2.3 STEAM DISTRIBTION SYSTEMS

Steam waste heat distribution systems are similar to district heating steam systems incorporating a steam line and condensate return.

Consideration must be given to collecting and returning the condensate and providing traps at the system low points. Peaking ability must be included either in the primary exhaust recovery boiler or along the distribution line. The advantage of steam distribution is the small line sizes which can be used in comparison to solid water systems. A disadvantage in some locations is the vulnerability to freezing if interruption should occur for a period of time. In addition, steam lines may require the services of steam fitters to operate.

2.4 COMBINATION STEAM/WATER SYSTEMS

In some cases it may be advantageous to supply heat from the plant via steam line to a central location and convert the heat to a hot water system for local distribution. This allows process steam to be available for special applications while eliminating the need for an elaborate condensate return network.

Depending on the customer/supplier relationship, it may be necessary to ensure that the customers' boilers do not supply heat to the main system during periods of low supply temperatures from the diesel plant. (This possibility exists where peaking boilers are not incorporated in the main system and the heat production is at a low point).

Figure (10A) outlines the typical control arrangement used to prevent such reverse heat transfer.

If an agreement can be made with the heat supplier, it is advantageous from a capital cost point of view to incorporate all customer boilers on the system as peaking boilers feeding heat into the mains. In some cases, the customers' original boilers are sufficient to carry the entire distribution network in the event of a failure of the plant waste heat recovery equipment.

2.5 PIPING MATERIALS AND METHODS

Although significant advances have been achieved in the design of polyethylene and plastic pipe, their properties remain severely restricted at normal operative pressures and temperatures encountered in distribution mains. However, extensive use is made of polyethylene tubing for customer in-slab heating where water temperatures are limited to a maximum of 30C. In such applications, the tubing is very effective both from a cost and performance point of view and is capable of using low grade supply temperatures.

Steel pipe remains the choice for distribution systems discussed in this report. The amount and type of insulation depends on ambient temperatures, system supply temperatures, the amount of heat surplus to market demand which can be wasted through line loss, and the minimum acceptable supply temperature for the most remote customer.

For supply water temperature of 95C and lower, polyurethene insulation is normally used with a protective high density polyethylene outer sheath for underground application. The above ground system uses a metal jacket outersheath from 30 gauge to 16 gauge depending on the severity of the application. For supply temperatures from 95C to 175C, (high temperature water and steam) isocyanurate foam or calcium silicate insulation is recommended.

The foam insulation systems are normally applied to the pipe at the factory so that only field connections require insulation and moisture protection during installation. Figure (11A) demonstrates the method.

In the case of utilidor application, the utilidor itself is usually insulated and may also act as the chase for the municipal services.

Pipe joining methods include mechanical grooved pipe with special gaskets and couplers, welded, and threaded. Underground piping is usually welded while above ground pipe may be mechanically grooved, threaded or welded. Threaded pipe is usually limited to 50 mm and smaller. Branch trees may be flanged, threaded, grooved or welded.

Allowance must be made throughout the system for expansion, venting and draining. In the case of steam piping, the pipe must be sloped towards low point traps throughout. For each branch take-off, isolation valves are provided.

Mechanically grooved piping does not normally require expansion loops as the joint is free to move within specified limites. Care must be taken during installation to compensate for the initial "slack" in the system and the temperature extremes to which the system will be subjected. When glycol is used with water, special gaskets are required.

The advantage of the grooved pipe system is that installation does not require skilled labour for joining, although the couplers and fittings are somewhat expensive. This system is not suitable for steam service. Welded pipe offers the most durable arrangement for distribution mains, and is the method recommended for underground application. Expansion arrangements must be designed into the system.

In order to conform to the local requirements of the generator ground grid and ground fault systems, dielectric couplings are normally installed at the utility fance, to meet the same requirements as the water, telephone and sewer services to the generator station property.

3.0 DIESEL GENERATOR WASTE HEAT RECOVERY CONVERSION EQUIPMENT

3.1 GENERAL OVERVIEW

The various types and combinations of waste heat recovery equipment and systems used in cogeneration design must be considered for technical, economical and practical reasons. Once the method has been decided, the following criteria will take precedence over all heat recovery considerations:

1. Engine operating temperatures and pressure must be maintained within acceptable limits regardless of the downstream demand for recovered heat.
2. Waste heat distribution system failures must occur in a manner that will neither harm the engine nor jeopardize the ability of the plant to produce electricity.

Heat recovery methods are generally grouped into normal temperature (90C) and high temperature (120C). High temperature methods can be further divided into hot water systems (120C and 130 kPa pressure) and ebullient systems (120C and 100 kPa pressure).

3.2 NORMAL TEMPERATURE RECOVERY

3.2.1. JACKET WATER RECOVERY

Normal jacket water recovery is essentially low-grade heat, usually supplied to the customer at 75C when exchanger losses are considered. Slightly higher temperatures are possible; however, the size of the heat exchanger becomes prohibitive to achieve temperatures which closely approach that of the engine coolant.

In retro-fit applications, very little floor space is required for hjeat exchanger installations. Because of this, most existing plants can accommodate the modification without problem. It is possible to connect more than one engine per heat exchanger, although most operators prefer to duplicate the engine cooling systems.

Costs for "jacket water only" recovery vary from $40 to $60 per kilowatt depending on the size and geographical location of the retro-fit. Figure (1A) describes a typical jacket waste system.

3.2.2 EXHAUST RECOVERY - NORMAL TEMPERATURE

Exhaust heat recovery equipment is designed to recover heat from the exhaust gas down to a temperature of about 170'C, which is above the condensation temperature of the gas stream.

Because of the corrosive nature of the exhaust gases, some designs have provision for maintaining the minimum outlet temperature such as by-passing some coolant across the boiler.

An exhaust boiler system offers a convenient opportunity to employ auxillary firing in the unit to supplement the system heating requirements when the demand exceeds the ability of the total energy system to supply.

It is recommended that each engine be equipped with its own exhaust boiler or heat recovery silencer. Experience has proven that it is very difficult to manifold several exhaust systems together and still maintain effective isolation of any engine not on the line.

Costs for exhaust recovery may vary from $80 to $120 per kilowatt depending on the size, location, and space requirements. Figure (2A) describes a typical exhaust boiler system.

3.2.3 COMBINED JACKET WATER AND EXHAUST RECOVERY - NORMAL TEMPERATURE

The addition of exhaust gas recovery to jacket water complicates the flow and controls slightly over either the simple jacket water or exhaust gas recovery.

Additional consideration must be given to the situation where the demand for waste heat is minimal while the engine is operating near load capacity. Because of the additional heat which must be rejected due to stack recovery, the retro-fit must also consider the requirements to keep the system within acceptable operating limits. This may mean the addition of supplementary radiators to the system either on the primary engine side or the secondary distribution network, or the inclusion of an exhaust by-pass pipe as shown in Figure (2A).

The advantage of combined recovery is that overall plant efficiencies can approach 75% if a sufficient market exists for the recovered heat. In addition, the distribution water temperatures coincide with those normally used in hot water system design (95'C) resulting in smaller distribution main sizes and lower pumping rates than with jacket water alone.

Costs for the combined jacket water and exhaust recovery normal temperature systems vary from $60 to $90 per kilowatt depending on size, location and space considerations. Figure (3) describes a typical combined system.

3.2.4 HIGH TEMPERATURE - SOLID WATER SYSTEMS

This system uses elevated jacket coolant temperatures up to 120C at the engine outlet and operates as a normal temperature hot water system except for the additional pressure required in the circulatory systems and engine coolant circuit to prevent the formation of steam.

Consideration must be given to the engine design to allow for elevated temperature operation in terms of gaskets, seals, coolant pumps and oil cooling requirements. In general, conventional water pumps and engine gaskets will not be suitable for this service and supplemental oil cooling will be required if not so equipped.

The advantage of high temperature recovery lies in the higher quality of heat produced to the distribution system, which reduces distribution costs and allows for some process application in terms of potential markets.

Because the high temperature systems operate close to the design limits of the engines, greater care is required in terms of safety shut down systems, maintenance levels and supervision of the engines' vital signs. In retro-fit applications for engines not fitted for such operation, it is unlikely that the average plant operator will look favourably upon high temperature recovery.

Conversion costs to high temperature recovery may be higher than those for normal temperature because of the possible requirement for engine retro-fit. Estimates range from $100 to $120 per kilowatt depending on size, location, and space consideration.

3.2.5 EBULLIENT SYSTEMS

This system utilizes the heat of vapourization to remove rejected heat from the engine. The steam is moved through the water passages along with high temperature water by thermal action to a steam separator located at an elevation somewhat above the engine. No jacket water pump is required with this system as flow is maintained by the change in coolant density as it gains heat from the engine. Most of the heat gain is added in the form of heat of vaporization. Figure (4) illustrates the process.

A number of arrangements are possible, the most common being an exhaust gas boiler and steam separator combined into a single package unit for each engine. Figure (5A) shows a typical system arrangement.

The ebullient system requires special consideration for the engine gaskets, and seals as well as special sloping header manifolds to collect the vapour at the top of the engine to ensure steam cannot be trapped in the engine.

The main advantages of ebullient systems are:

1) smaller distribution lines and heat rejection devices;
2) less expensive to control;
3) less parasitic power required to circulate coolant through engine jackets; and
4) higher grade of heat for process application; especially the mining industry.

The disadvantages of the ebullient systems are:

1) oxygen entering through open vents and makeup water to replace lost condensate contaminates the system. Scale formation can result causing hot spotting and thermal distortion of cylinder lines and jackets;
2) fast acting back pressure valves are required to maintain a constant fluid/steam level above the engine regardless of steam consumption, and
3) steam systems may require that the plant operator maintain a stationary engineer with a steam ticket to service and operate the recovery equipment.

From a practical point of view, ebullient systems will not normally be preferred by the average plant operator for retro-fit application.

Costs for converting a conventional diesel plant to the ebullient system may vary from $150 to $250 per kilowatt depending on size, type, location and space considerations.

3.2.6 EXHAUST RECOVERY ONLY - STEAM

Exhaust recovery equipment for steam production is similar to exhaust equipment used for solid water.

The advantage of steam production from exhaust is the high quality of heat which can be produced for process application. As the pressure of the supplied steam increases, the recovery efficiency and volume of steam decreases.

Aside from a slight decrease in engine performance due to increase exhaust back pressure, exhaust recovery does not normally require engine modifications to implement. Provisions must be made to reject surplus production when engine heat output exceeds demands from the system. Concersely, peaking steam boilers may be required when demand exceeds supply.

As with the ebullient system for jacket recovery, makeup water required tratment to prevent boiler systems fouling.

Figure (6A) shows a typical steam only exhaust recovery system.

4.0 DESCRIPTION OF A TYPICAL COMMUNITY WASTE HEAT RECOVERY RETRO-FIT PROJECT; CAMBRIDGE BAY, N.W.T.

4.1 GENERAL

The object of this section is to outline the typical technical, financial and administrative considerations to be addressed to complete a cooperative community waste heat recovery retro-fit project.

4.2 BACKGROUND

Motivation for the Government of the Northwest Territories

(G.N.W.T.) and Northern Canada Power Commission (NCPC) to consider diesel generator waste heat retro-fit was precipitated by the rise in fuel prices during the seventies. Since most of the communities throughout the N.W.T. derive electrical energy from fossil fuels, it is apparent tha the north faces a certain operational cost vulnerability for which there are no realistic alternatives for the forseeable future.

As part of a comprehensive look at energy conservation, the G.N.W.T. decided to study the possibility of waste heat recovery from community generating plants in 1976. The emphasis was to be on retro-fit of existing buildings and equipment.

4.3 PRE-DESIGN INVESTIGATION

The preliminary work centered around potential site selection and recovery techniques to be used. The intent was to view the project as an experimental pilot system on which to base future conversions.

From the beginning, it was apparent that the project depended on the supplier (NCPC) and the user (G.N.W.T.) reaching a satisfactory arrangement technically, administratively and financially. The supplier and user had different and sometimes conflicting interests. NCPC wanted to protect their engines, keep maintenance costs down, and eliminate system complications. The G.N.W.T. wanted high grade heat to minimize distribution and conversion costs and a guaranteed supply of heat. It was therefore important to realize a mutually acceptable design for both parties, even if it meant compromising the most efficient technical solution. The site selection for Cambridge Bay reflects this approach.

The choice represented the types of building conversions likely to be undertaken in future: hot air, hot water, external piping between buildings, below grade, above grade and across roadways.

4.4 PRELIMINARY DESIGN

During the preliminary design stages, it was decided to utilize only the engine coolant water heat and not the exhaust gas heat. The decision was based on four considerations:

1) As a pilot project, use of the lower grade heat was desired to obtain operating data on a simple form of recovery;

2) The total building requirements could be handled by the rejected coolant heat alone.

3) The capital cost per BTU/annum was lower for engine coolant recovery only. It was also technically straightforward.

4) NCPC felt that "coolant only" recovery would not affect engine performance nor require changes to their basic method of operating.

The buildings connected to the system were known to be uncomfortable, drafty and very heavy fuel users, consuming in excess of 50,000 gallons per annum. To keep the project results in context, no building retro-fitting was allowed until at least one year of operating data was obtained.

4.5 DESIGN

It was agreed with NCPC that "in-plant" modifications would follow those outlined previously in Figure (1A) of this report. This decision set the system distribution water temperature at 70°C and was used in the design of the various building retro-fit requirements. Distribution mains were sized in accordance with the required flows and pressure drops for the network.

The main garage in Plan 1 houses the main distribution pumps for the system. Since the garage had hot water boilers originally, connection to the system was made according to Figure (9). As the waste heat supply temperature was lower than the existing design, one extra unit heater was included to provide the same level of heating.
The supply warehouse was heated by a large hot air furnace which was modified in a manner similar to Figure (8A) with an additional three way walve to control the supply air temperature on a continuously operating fan. In the event of insufficient heat, an end switch on the thermostat starts the burner. In addition, one unit heater was added near the main loading door for pickup purposes.

The tradeshop was connected in a manner similar to the main garage. Both boilers are capable of maintaining the distribution system at design temperatures in the event of inadequate heat from NCPC.

The vehicle storage and carpenter shop were originally heated by hot air furnaces left in place to act as backup. These buildings were retro-fitted with sufficient overhead unit heaters to maintain temperature via the recovery system.

The system was filled with 50% glycol, a normal practice for Arctic installations. As the soils were thaw-stable, outside mains were shallow buried with factory applied insulation. Due to the difficulty of arranging welding in Cambridge Bay, it was decided to use mechnical grooved pipe with special gaskets for hot glycol application covered with urethene half shell insulation and heat shrink sleeves per Figure (11A). Using this system, no expansion service loops were required. Makeup water and system expansion were included in the design in accordance with good engineering practice.

4.6 SYSTEM EXTENSIONS

The system has expanded to include heating of the municipal water supply and a new community office complex. The extension remains a hot water system with a maximum useable recovery rate of 600KW waste heat.

4.7 COST/BENEFIT ARRANGEMENTS

The responsibility for the system was broken down as follows:

1) All modifications and maintenance behind the powerhouse wall were the responsibility of NCPC.

2) The distribution lines, pumps, and equipment from the powerhouse wall were the responsibility of the G.N.W.T. for cost and maintenance.

Because NCPC and the G.N.W.T. would both benefit from the recovered heat through increased cash flow or cost avoidance, it was agreed to have the G.N.W.T. pay 50% of the equivalent fuel cost for the heat received and used.

Subsequent heat recovery projects, such as Rankin Inlet have a different financial arrangement. NCPC requires the customer to pay 100% of the capital modification costs for heat recovery including in-plant modifications and 50% of the equivalent fuel value of heat recovered. In return, NCPC allows for "free heat" for a period of time which will help amortize the customers' capital investment.

4.8 SUMMARY

Now that the pilot project has been in operation for over six years, it is evident that the system requires very little attention, performs as predicted and has received unqualified acceptance from both NCPC and the Government of the Northwest Territories at the local level.

5.0 REVIEW OF LAC LA MARTRE SCHOOL WASTE HEAT RECOVERY PROJECT

Lac La Martre, like many northern communities, is not served by an all weather road. The only access is by air or by the winter ice road which is open approximately two months of the year. The town's clay and gravel airstrip is too short for a Hercules or DC3 aircraft so that the only economical haulage route is via the winter ice road.

As the town is isolated, the cost of flying in materials and maintenance staff is high. Therefore, the mechanical system design for both the school and the heat recovery equipment incorporated into the NCPC plant, had to be kept as simple and maintenance-free as possible and still meet the energy objectives.

On the other hand, due to the unfavourable climate, the high cost of electricity and fuel oil, the school design required the incorporation of a high degree of energy conservation and associated controls to maximize use of the waste heat available. It was considered that the advantages of much lower running costs would outweigh the disadvantages of more sophisticated controls.

The consultants and NCPC co-ordinated the design through the initial stages. NCPC were responsible for all the work associated with their equipment, including the design and installation. NCPC are obviously concerned about the effect any modification work would have on their equipment and it is important that they are fully involved at the design stage in order that no maintenance problems are created by any alterations.

A design balance was required that would prove to be acceptable to all parties - the community, the maintenance staff, NCPC, GNWT and the design consultants.

5.1 PRE-DESIGN INVESTIGATION

The project depended on the supplier (NCPC) and the user (GNWT) reaching a satisfactory arrangement technically, administratively and financially. The supplier and user had different and sometimes conflicting interests. NCPC wanted to protect their engines, keep maintenance costs down and eliminate system complications. The GNWT wanted a sufficient supply of high grade heat with as few technical problems as possible.

5.2 PRELIMINARY DESIGN

The siting of the school in relation to the NCPC plant provided a straightforward solution to the routing of heating lines between the school and the NCPC generators. The pipes would be buried beneath the playing fields, entering the school through the crawl space, where they provided partial heating, before passing into the boiler room. (See Figure 3).

Preliminary load calculation revealed the need to use both the waste heat from the generators' coolant water and the flue gas. (See Figure 7). In all projects previously handled, the jacket water heat was more than sufficient to handle the market requirements. This was the first attempt to be made to incorporate an exhaust boiler in a retro-fit project, and complicated the recovery process from NCPC's point of view vis-a-vis the unknowns about remote plant reliability.

5.3 SCHOOL HEATING SYSTEM

Apart from certain additional energy conservation measures which have been incorporated into the mechanical design the school's heating system consists of conventional perimeter baseboard heating, together with two ventilation systems supplying tempered outside air as required.

The domestic hot water is supplied by the wate heat with cold water being circulated through tankless heat exchangers and stored in insulated tanks. An electric heater was installed as emergency backup only.

5.4 NCPC TO SCHOOL HEATING PIPES

The heating system is filled with a pre-mixed solution of 50% propylene glycol and 50% water. Freezing of the heating fluid is not a risk so that any insulation provided around interconnecting piepwork is for heat loss purposes only.

Pipe: 63mm schedule 40 welded steel pipes.

Insulation: 38mm thick polyethylene insulation and 45 mil polyethylene black jacket. The black jacket is more resistant to ultra-violet light than the yellow jacket and was chosen because it was anticipated that the pipes would be stored in the open for a few months before installation.

Pipe Depth: 600mm

Installation: Soils are not thaw stable in permafrost so that timber sleepers were used, extending beyond the influence of the thaw bulb created by the pipes.

See Figures (3) and (4) for further details.

5.5 SCHOOL HEATING SYSTEM OPERATION

The school heating system was designed to be completely self-contained, with two oil-fired boilers capable of providing the necessary heat. However, the intention of the design was to use as much of the waste heat from the NCPC generating plant as possible. This would mean that the school boilers' operations would be kept to a minimum. It was anticipated that some peaking at design conditions would be required from the boilers.

The school heating system was designed to operate at 62C which could normally be supplied from the NCPC recovery lines. (See Figure 6).

The hot water passes in series from the NCPC recovery lines through the boilers, which will make the water up to 62C, with an operating aquastat controlling the boilers when NCPC cannot supply enough heat. It was anticipated that this situation would only arise on the colder winter days when the generating plant was operating at a low capacity such as mid morning, mid afternoon and after midnight.

If the NCPC water temperature supply falls below 49'C, the heat recovery line aquastat modulates a 3-way valve to recirculate the water back to NCPC rather than through the school heating system. This is to prevent the situation where the heat flow is reversed, and the boilers are providing heat to the NCPC plant.

The school heating system has separate pumps. The additional pumps which circulate the hot water betweenh the school and the NCPC building are also situated within the school boiler room.

A thermostat located on the heating water supply line will initiate an alrm when the temperature drops below 43'C.

With the incorporation of the night setback features, the generator supply and school demand are in phase both daily and seasonably. For this reason, analysis has shown that storage is not a significant issue.

5.6 NCPC HEAT RECOVERY SYSTEM

Due to the heating load and plant heat output, it was necessary to recover the waste heat both from the generators' jacket water and from their exhaust flue gas. It is our first major project to use both waste heat sources from the town's main diesel generating plant in a retro-fit application.

The primary concern of NCPC was that the new equipment would not adversely affect the operation of the generating equipment. They did not want increased maintenance costs imposed by unreliable equipment and intricate controls, and also needed assurances that the connecting system would be perfectly safe.

These usual NCPC conditions indicated that the school heating system would be on a self-contained secondary system, making possible complete isolation should future problems from either system arise. Instances such as leaking engine oil into the jacket water, or breakdown of the school circulating pumps, would be isolated.

The engine operating temperatures and pressures must remain within acceptable limits, regardless of downstream demand for the recovered heat. Controls and interfaces were required to operate in such a way that failure would occur in a "safe" direction to protect the generating plant.

From preliminary calculations it was seen that not enough heat would be rejected from the jacket water to totally heat the school in winter. The water cooling circuits remove 30% of the energy input to the engine. Engine operation must be kept fairly constant at 70 to 90C. It is important that the jacket water not be over cooled. Temperature differences between water inlet and outlet to the engine should be between 5.5C and 8.3C.

The school heating system has a high thermal inertia modulating slowly with outside temperature variation. A "buffer" storage tank, which helps to minimize thermal stresses to the engine due to quickly changing loads, was therefore unnecessary.

The exhaust gas also has limitations as to how much heat recovery can be allowed. 50 - 60% of the gas heat can be recovered depending on the initial temperature but the gas temperature must not fall below 170C, which is still above the condensation temperature of the gas stream.

The primary aim of the exhaust heat recovery design should be to minimize the back pressure introduced, since restriction of the exhaust gas flow causes loss of horsepower and increased operating temperatures, with uncertain effects on the exhaust valves.

5.7 OPERATION

The school heating system is connected to the generators' motors cooling water system via a plate heat exchanger. This is the primary heat source. At the design stage it was anticipated the additonal heat output from the flue gases would also be required during the colder winter months. As explained later in the report, the exhaust boiler is being used in summer as well.

Generally NCPC prefer to duplicate their engine cooling system so that a leak or breakdown in one system does not totally break the town's electrical supply. The generating system was considered too small in this case as one outdoor radiator adequately rejects all the jacket water waste heat.

During design, every load condition must be considered. When the generator output is large and the school load is minimal, a situation would arise where the radiator would have to reject both the jacket water heat and the heat from the exhaust boiler. The existing radiator is not large enough and the alternative of incorporating a bypass to the exhaust boiler was used. A control valve diverts the flue gas to atmosphere via a conventional muffler when heat recovery is not called for.

5.8 NCPC GENERATING EQUIPMENT

There are three generators which handle the total power supply for Lac La Martre:

#1: Make and Model: DD4-71 (4 Cylinder)
: 80 KW @ 600V and 1800 RPM
: Equipped with "Tamper" 125 Kva generator.

#2: As #1.

#3: Make and Model: Caterpillar D-342 (6 Cylinder)
: 150KW @ 600V and 1200 RPM
: Equipped with "Kato" 187.5 Kva generator.

Units #1 and #3 are hooked to the heat recovery system.

NOTE: In May 1983, the generating system was upgraded. Generator #1 was replaced with a larger unit; Caterpillar 3406 with 281.25 kVa generator. This new unit was hooked up to a new outdoor radiator and connected into the existing heat recovery system.

There was also much general upgrading performed at this time, with new gauges, access ladders and monitoring equipment.

5.9 SCHOOL HEATING EQUIPMENT

The school is provided with two boilers which are sized to handle the complete heating load.

#1: Weil-McClain Model "ABL976-W-T1H" with 159 KW output.

#2: As #1.

5.10 CIRCULATING PUMPS

Two pumps were installed in the school boiler room to continuously circulate the waste heat from the NCPC building to the school.

Pumps (one standby): Armstrong H54.
Capacity 2.53L/S @ 7.9m head
3/4 HP, 208V/3/60 motor.

5.11 POSSIBLE ANALYSIS FROM READINGS

Once a set of readings is obtained over a particular time period, there are certain conclusions that can be drawn and assumptions made.

Two readings of water flow rate cubic (meter) over a specified time period tell us the flow of hot water being passed from the NCPC heat recovery equipment into the school.

If we know that the school boilers have not fired during the measured time, then the water supply and return temperatures, together with the water flow rate, can tell us the heating load of the school over that particular time period. We use the following equation:

$Q = m.s.dt$ (1)

Where Q = School heating load (kilowatts).
m = Flow rate of the hot water (litres/second).
s = Specific heat of water (4.18 kilojoules/kilogram C).
dt = Difference between water supply and return temperature (C).

Whenever the NCPC waste heat is insufficient to heat the school, the boilers will fire and readings from the oil meter, connected to the inlet of the day tank, will enable us to calculate the amount of supplemental heat and oil consumption, over the heating season.

The Heat Load, read from the meter in Megawatt Hours (MHW) tells us the total energy absorbed by the school from NCPC's waste heat.

> For example: If the school heating load over a period of 3 hours was a constant 150 KW, the total energy absorbed in that time would be 450 KW hours or 0.45 MW hours.

5.12 SITE VISITS

Winter 1983

The results of this site visit are given in Table 1.

Observations With the outside temperature at -24C, this could be considered a fairly typical winter's day. Our first observation, as we walked past the NCPC generating building was how quiet the equipment was. All the flue gases were being discharged through the heat recovery silencer and as a result the "bypass flue" was icing up due to infrequent use.

The school boilers did not fire during our 1 1/2 hours stay showing us that the school was being totally satisfied by NCPC's waste heat.

It was also noticed that the NCPC radiator, which is normally used to dissipate the engine's waste heat, was cold. From this observation, we made the assumption that the total recoverable heat from the generating plant was being used by the school. When the load on the generator at the time was 100KW, or 66% load.

Calculations

In addition to the information shown in Table 1, the following readings were recorded.

Average No. of Degree Days in January = 1360
Outside Temperature = -24'C
Predicted No. of Degree Days for
January 7, 1983 = 18 - (-24)
= 42

NCPC Readings: Generator Electrical Output = 100 KW
Water Temp. into Plate
Heat Exchanger = 50'C
Water Temp. out of Exchanger = 60'C

Water Temp. into Exhaust Boiler = 60'C
Water Temp. out of Exhaust Boiler= 65'C

From all these readings we can calculate the following:

Heating Water Flow into School = 8.5m3 in 67 minutes
= 2.11 L/S

School Heating Load = m.s.dt
At -24C Outside Temperature = 2.11x4.18x15
= 132.3 KW

Summer 1983

Observations

The outside air temperature was 15C which is typical for a summer's day in Lac La Martre. At the time of this visit the NCPC building was in the process of being upgraded. New gauges and metering equipment were being installed and the staff are obviously taking a close interest in how the heat recovery system is working and how it is affecting their equipment. One of the smaller generators had been replaced by a larger model (See System's Design) and it's engine connected into the heat recovery system. A new outdoor radiator had also been installed for the new engine.

Both the radiators were cold and we were surprised to find that the exhaust boiler was being used. The flue gas temperature dropped from 300'C to 180'C through the exchanger. Actual water temperatures could not be taken as the gauges had temporarily been removed.

At the school we found both ventilation supply fans operating, together with both the pumps for the heating coil circuit and that for the radiation circuit.

The load on the one generator that was running was 65 KW, or 43% load.

5.11 NCPC WINTER SITE VISIT

New information is constantly being obtained through site visits, NCPC and communication with the school. A 3-day site visit by NCPC's maintenance staff in February provided us with some valuable information. The observations that were recorded included:

1. During the hours 0900 to 1900, the school's heat demand was sufficient to ensure complete engine cooling.

2. During the hours 1900 to 0900, the NCPC plant's cooling system, i.e., the radiator, is utilized on an intermittent basis.

3. The NCPC loads ranged from a low of 80 KW to a high of 145 KW. Generally the steady day and night loads were 100 KW and 80 KW respectively.

4. The boilers did not fire during the 3-day visit. The outside day temperatures averages -20'C falling to -30'C at night.

5.12 INTERIM PREDICTIONS (February 1983)

In February, in the middle of the heating season, the following observations were made from the predictions produced in Table 2.

"The NCPC Heat output will totally satisfy the school's heating requirements during the months April-October. The 'supply' and 'demand' figures are far enough apart for us to confidently assume this to be the case. In fact, it is possible that the generator's jacket water waste heat will be sufficient to provide the heat requirements.

As the temperature falls in November, the school heat load climbs sharply and it is possible that the boilers will be required to fire occasionally to handle instantaneous peaks.

During the winter months of December, January and February, the NCPC waste heat should still provide the majority of the school's heat source, but the boilers may be required to handle peaks as required.

As outlined in the "Limitations" of this section, the tables do not tell us what is happening from hour to hour. The generating output is not constant, but rises and falls during the day and night. Similarly, the school heat requirement changes withj temperature, wind, occupancy and night setback. There ,may be times when the school has surplus heat from the plant, and others when additional peak heat is required".

5.13 INTERIM OBSERVATIONS OF SYSTEM PERFORMANCE (February 1983)

After 3 months of operation, the systems were working more efficiently than was anticipated. During these early stages, many parties kept a close watch on operation and the general opinion was one of complete satisfaction.

NCPC reported no problems, and indicated that the generators' engine operating temperature was being maintained at a satisfactory 80'C with flue gas temperature fairly steady at 210'C. The exhaust recovery unit helped to dampen the noise transfer from the generators to outside, and the engine noise was almost inaudible when standing outside the NCPC enclosure.

The school was designed to operate at a water supply temperature of 62C. However, on a winter visit, when the outdoor temperature was -24C, the boilers were not operating and the building appeared very comfortable at a water supply temperature of 60C.

From the period of initial operation of the school heating system on September 20, 1982 until the end of the year, the system was "on trial". Various parties were concerned that the optimum balance between the available NCPC waste heat and the school heating requirements should be obtained. As a result the system controls were continuously altered to attempt to find the best settings. Initially, the building was heated using only the jacket water exchanger and this provided 100% of the heat up to the end of November.

It was not until January 1983, when the school classes were gradually being transferred to the new school, that the heating system could be accurately monitored, with both the jacket water and exhaust recovery operating.

A site visit was made on January 7, 1983 and the school's maintenance engineer was asked to begin taking daily readings as his duties permitted. Table 1 shows the information that was recorded from within the school boiler room.

Readings taken during this visit also enabled the engineers to begin evaluating the system over the future months.

5.14 ANALYSIS

The electrical load of the town's generators, together with the school's heat requirements, are constantly changing throughout the day and the year.

It was found that the NCPC load, and the school heat requirements, are in phase despite all the variables which have to be considered. As the outside temperature falls, NCPC waste heat increases at a similar rate to the school heating load. As the temperature rises, the opposite occurs.

The actual quantity of heat supply and demand are very well matched, particularly in the winter months when this is most important. It appears that for much of the time, the total heat given up by the NCPC engines was used by the school. Only very rarely was the demand higher than the available heat supply, and it was only at those times that the school boilers were required to operate.

5.15 WINTER OPERATION OF HEAT RECOVERY SYSTEM

As mentioned during one of our winter visits, it was detected that the NCPC radiator was cold and we made the assumption that the total waste heat was being given up to the school. In other words, at an outside temperature of -24'C. 100% of NCPC's waste heat is recovered by the school at 66% generator.

From the readings, the heat recovered from the generators is as follows:

Q = m x s x dt (2)
Jacket water = 2.11 x 4.18 x 10 = 88.2 KW
Exhaust Gases = 2.11 x 4.18 x 5 = 44.1 KW
Total Heat Recovered 132.3 KW

There are some line losses between the NCPC plant and the school as the pipes pass underground for approximately 100 metres. However, the losses are so small that the meters cannot detect them. By calculation we predict the total loss from the interconnecting pipes to be approximately 3 KW.

The relevant informatoin is therefore:

Generator Electrical Output = 100 KW
Total Heat Recovered = 132.3 KW
Outside Temperature = -24'C

We have assumed that 100% of the heat output is being recovered, therefore it can be said that:

> For every 1 KW of generator electrical output, 1.32 KW of recoverable waste heat is produced.

From this statement, the quantity of recoverable heat can be ascertained from the predictions of monthly electrical output. The interim predictions of electrical output and recoverable heat and the associated relationships, are tabulated in Table 2.

The total generator output for January 1983 was 53,325 KWH (as recorded by NCPC).

Using an "1.32 KW heat output per 1.0 KW load" equation:

January waste heat available = 53,325 x 1.32
= 70,389 KWH

From our readings over the period January 7 to January 31, 1983 (see Table 1) the energy input into the school from the NCPC plant was:

$$\text{January school load} = 48{,}870 \times \frac{1{,}371}{1{,}105} = \underline{60{,}634\ \text{KWH}}$$

Where the number of degree days in January was 1,371.

So our estimates for January are:

Generator heat output = 70,389 KWH
School heat requirements = 60,634 KWH

The figures tell us that overall, the waste heat from the generators is adequate for the school. We know from our observations that there i8s an excess waste heat at night, which accounts for the difference in figures. However, we must not discount the possibility that there are occasional times when, during an extremely cold spell, the generator heat is not sufficient to totally heat the school (although there is no firm evidence to date that the boilers have been required to fire, to make up the water supply temperature).

5.16 SUMMER OPERATION OF HEAT RECOVERY SYSTEM

The school heat requirements over the summer months, shown in Table 4, are significantly higher than had been predicted. The major reason for this is the fact that the ventilation equipment has been used to a much larger extent over the summer months than had been anticipated. It was assumed that the ventilation fans would be switched off during the school summer break and so the school heat demand would be very light.

It appears that the school is being used for various other activities in the summer and the fans are generally kept on their automatic mode (that is, continuous daytime use). During one of the summer inspections, when the outdoor temperature was 15'C, the ventilation system certainly worked well in preventing a heat build-up within the school.

The ventilation controls are designed so that when the outdoor temperature rises above a certain setpoint, the fresh air damper opens to 100% position, to make use of as much free cooling as possible, when required. The total air quantity, however, of 7.2 cu.m./sec., imposes a sizeable heating load on the air coil, if ever the outdoor air temperature falls just a few degrees. This heating load is apparent in Table 4, and was not anticipated at the design stage.

If it was wished to decrease the school's ventilation heating load in the summer, it would be simply a matter of adjusting the setpoint of the outdoor air temperature sensor. If it is intended to operate the fans in the summer, however, then the dissipation of the heat in the coil is a bonus. This heat is the exce4ss heat from the NCPC plant and the radiators would normally be required to reject it to atmosphere. 5.17 LIMITATIONS OF ANALYSIS (An interim collection of comments concerning the Analysis - February

1983).

If the only concern of the project is the amount of financial saving which come about from the school's decreased oil consumption, then at the end of the first year an accurate figure of fuel saved and hence financial savings shall be available, and shall give that information.

However, if the results of this project are going to help determine the design and control systems of future heat recovery projects, then we need to try and understand exactly what is happening during different times of the year and at different outside temperatures.

The more readings that can be taken, particularly during the winter months when the NCPC waste heat cannot always supply enough heat, the more accurate are the assumptions as to how the system is behaving. Unless somebady is taking readings 24 hours a day, then these assumptions must be made.

The heat equation, Q=m.s.dt assumes that the school Heat Load is proportional to the difference between the inside and outside temperatures (dt). As we like to keep the inside temperature constant, we can say that the school heat load is proportional to the outside temperature. So now all we need are a few readings of the school load at various outside temperatures, in order to obtain an accurate picture of the school's behavior at varying outside conditions, and whether or not the load is linear.

It must be remembered that "night setback" is incorporated into the school's heating design and during the night, as the outside temperature falls and the generators' output fall, that predictions must be made.

The community's generators' electrical load, and therefore their waste heat output, is not as predictable as the school's heat load.

The generators' load is constantly varying, during the day, during the night, and over the whole year. During the day, peaks occur at eraly morning and early evening when there is maximum cooking, washing, etc. The load also increases as darkness falls, which occurs at a different time each day. Also the generators' load changes as the outside temperature varies, although this is not as linear a relationship as was the case for the school.
So it can be seen that although the school heating load is relatively easy to predict, the heat available from the generator

plant is less easy to foresee. NCPC shall provide the year's electrical loads at the end of the year, thus allowing us to calculate the waste heat outputs available.

One other point which has to be taken into account concerns "degree days". For a particular day, the number of degree days is the difference between the average temperature for that day, in degrees celsius, and a base temperature (18'C). For example, if the average temperature one day was -20'C, then it is said there were 38 degree days for that day.

An accurate set of figures of degree days can be gathered for the year. However, it must be remembered that the figure is based on the average outside temperature and it does not tell us how the temperature varied when it fell below that average value. We would need to know the full set of temperatures during the day and night in order to predict how the heat recovery system performed. As this is obviously too impractical, assumptions and guesses must be made.

Having listed the limitations of the readings and the consequient assumptions that must be made, it must be said that by the end ofd the first year, when all readings have been gathered and visual accounts are available from site visits, the analysis will provide a more accurate account of the heat recovery system's operation.

5.18 CONCLUSIONS - August 1983

Now that the data for the whole heating season are available, we can see that many of our concerns regarding the inaccuracy of the results are unfounded. Despite our lack of data at precise times of day and night, we are still able to obtain a valid picture of the operation. The general observation that the generator heat output and school demand are in phase with one another is the most important factor.

5.19 ENERGY SAVINGS ANALYSIS

We can now look at the energy savings predictions made at the beginning of the project and compare them with what actually happened over the first heating season.

As previously stated, no oil was transferred to the day tank from the main school storage tank throughout the whole winter. The only oil that was used was some of that originally contained in the day tank.

On January 7th, 1982 the oil level was 850 litres.
On July 7th, 1983 the oil level was 480 litres.

So the annual oil consumption for the school was only 370 litres.

Due to the lack of use of the school boilers, the school maintenance engineer was asked to operate them each weekend, in order to check their working condition. According to the engineer, the only other times that the boilers were seen to fire was when the outdoor temperature dropped to the high -30'C's.

The unexpected use of the ventilation equipment in the summer and the associated pump operation, was an added cost but unrelated to the heat recovery system costs.

Tables 1-5 give data, interim predictions and our up-to-date calculations.

5.20 UPDATED FINANCIAL SAVINGS - August 16, 1983

Cost to Heat Building Using Only Boilers Without Combined Waste Heat Recovery

Fuel Oil required: 50,150 litres/year
(88% of original estimate)

@ $0.580/litre $29,,087

Boiler operating time: 2,658 hours @ 0.25 KW
= 665 KWH @ $0.573 $ 318

Oil transfer pumps: 160 hours @ 0.5 KW
= 80 KWH @ $0.573 $ 46

Total Heating Costs (Incl. Electrical Power) $29,451

Energy Efficient Alternative: using NCPC waste heat

Fuel Oil required: 370 litres/year
@ $0.580/litre $ 215

Boiler electrical and transfer pumps:

6 KWH @ $0.573 $ 3

Recirculating pump: 0.56 KW for 365 days
= 4,906 KWH @ $0.573 $ 2,811

Total Cost Using Waste Heat $ 3,029

Therefore: Net savings are:

$29,451 - $3,029 = $26,422/annum.

This compares with a predicted figure of $18,854/annum.

NCPC have waived the 50% charge on waste heat, so the full saving can now be realized by GNWT.

In the financial evaluation it must be noted that the final cost of the heat recovery equipment and installation was $249,000 compared with the $60,000 initial input.

5.21 CONCLUSIONS

1. Now that the school has operated through a whole winter season, the project can be considered a success to this point. NCPC are reporting no problems; the design consultants are pleased with the system operation and the community and GNWT are benefitting from the low fuel usage of the school.

2. The recoverable heat from the generating equipment appears to be approximately 10% lighter than anticipated. Considering this, and the fact that the school loads are only 60% of initial calculating, NCPC's waste heat is almost totally satisafying the school's heat requirements.

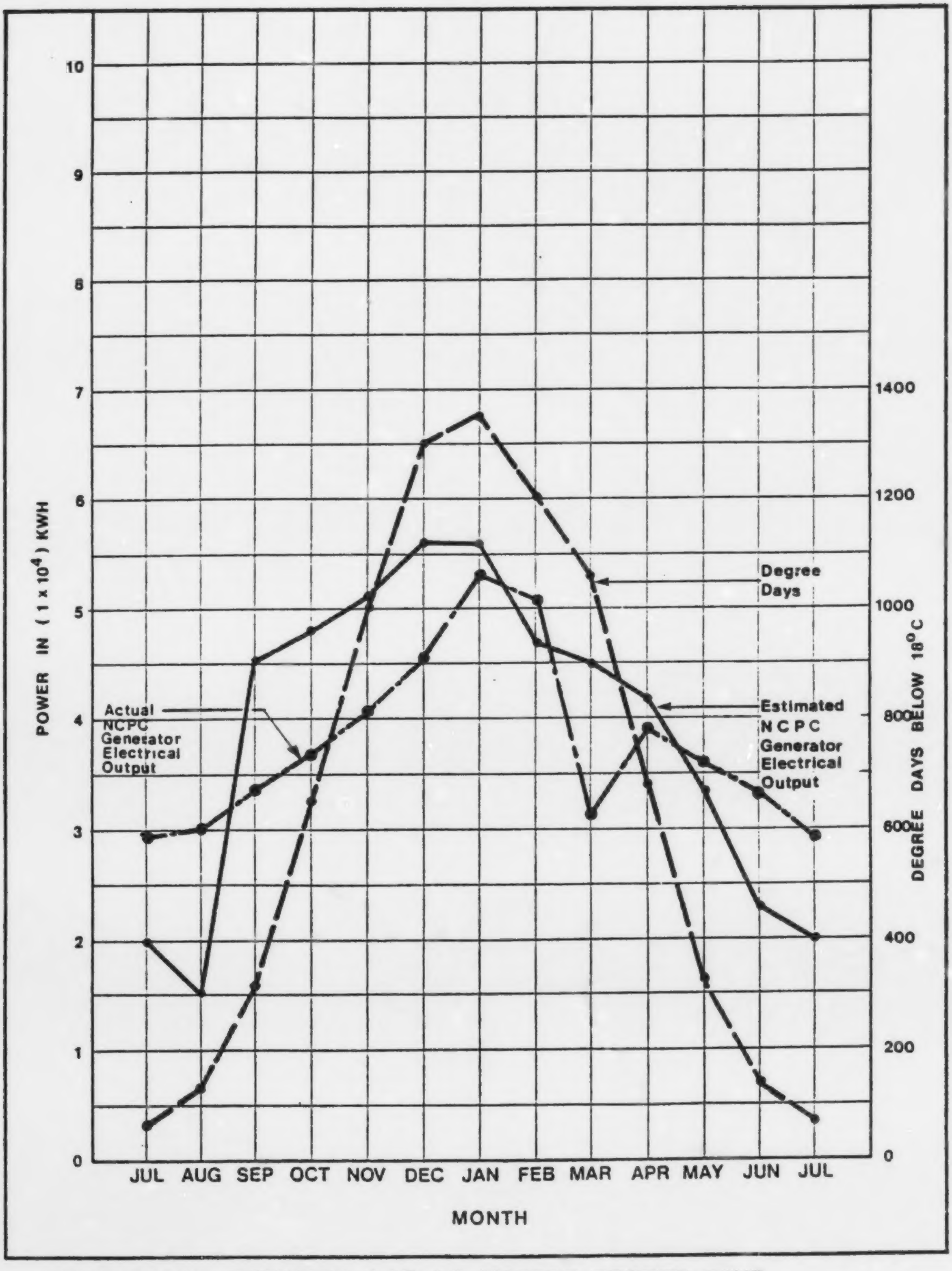
3. Payback period is approximately 9 years. This is higher than had been anticipated due to the installed capital cost of the heat recovery system being nearly 400% higher than first estimated. Another factor is the fuel inflation rate which has dropped from previous values.

5.22 OBSERVATIONS

The project was designed, installed and is now operating full time. In retrospect, we feel the following observations are:

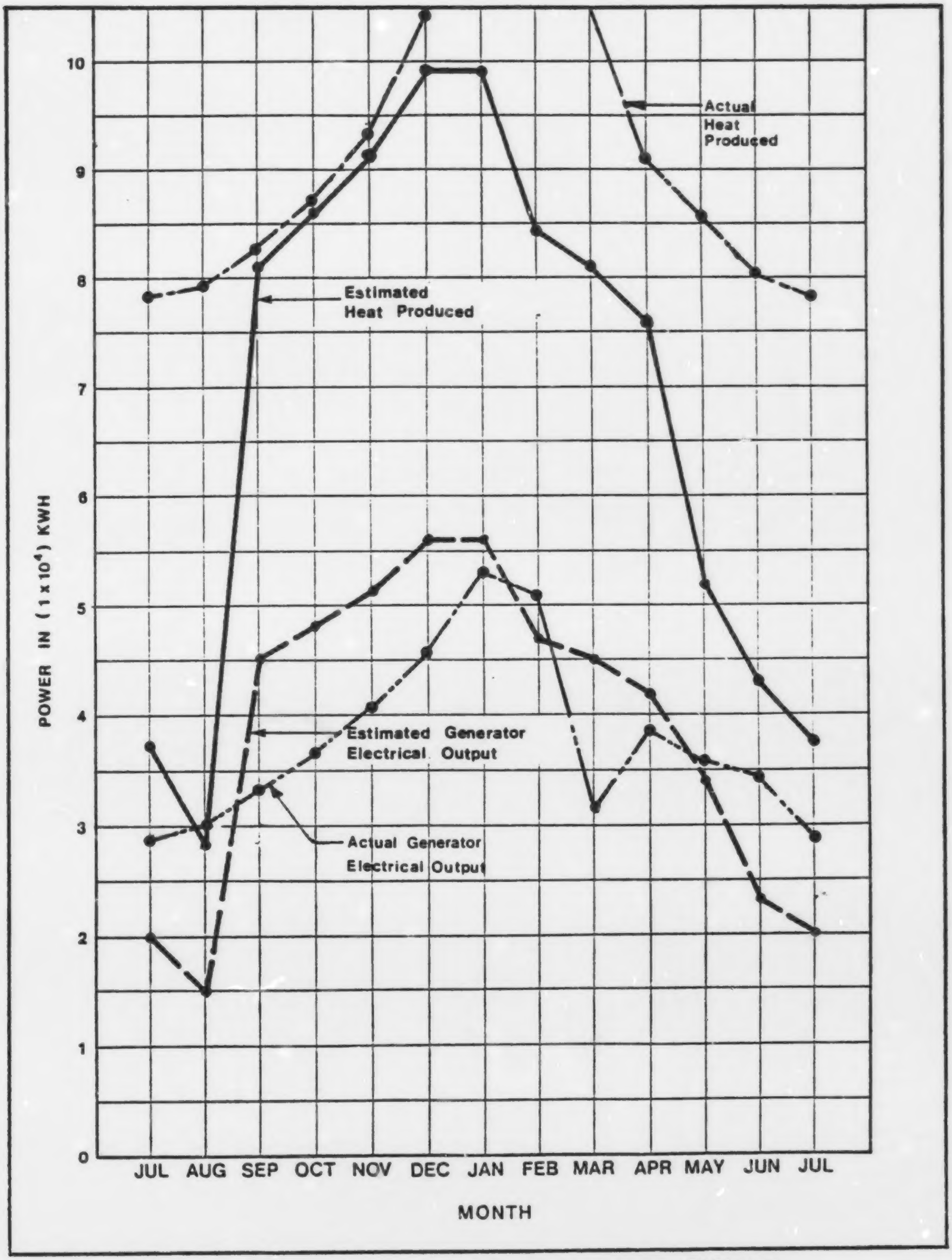
1. One of the major reasons for the success of this project, was the co-operation shown between all parties throughout the job. It should not be underestimated how this can improve all stages of the project.

2. We feel that it is important that the Power Commission control the design for the in-plant portion of the work. Only they know what future space requirements they have in their generating buildings. Their knowledge of the equipment and the fact that they would be responsible for future maintenance makes it important that they control all of the in-plant work.



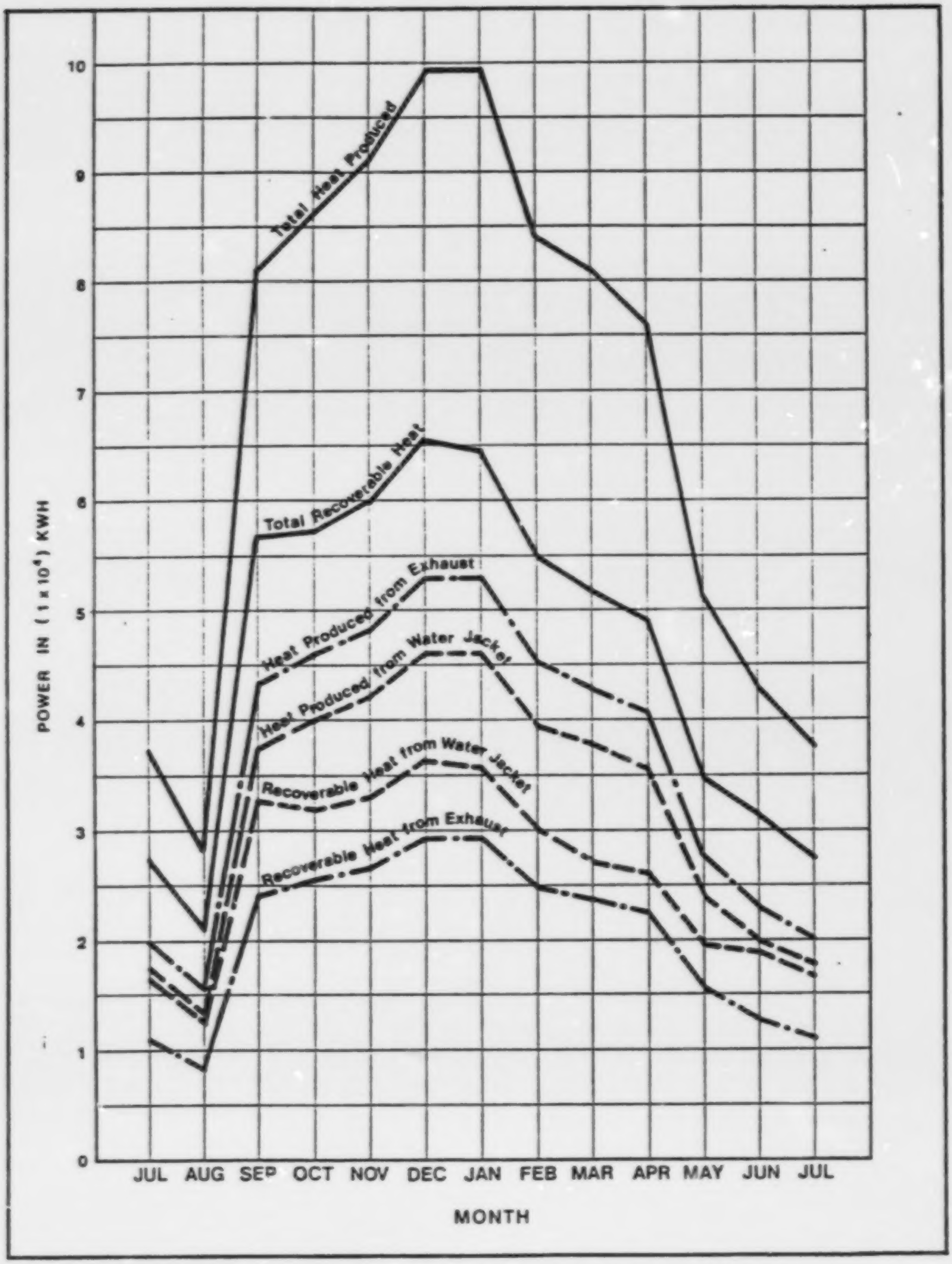
RELATIONSHIP BETWEEN LAC LA MARTRE DEGREE DAYS and N C P C ELECTRICAL OUTPUT

GRAPH 1



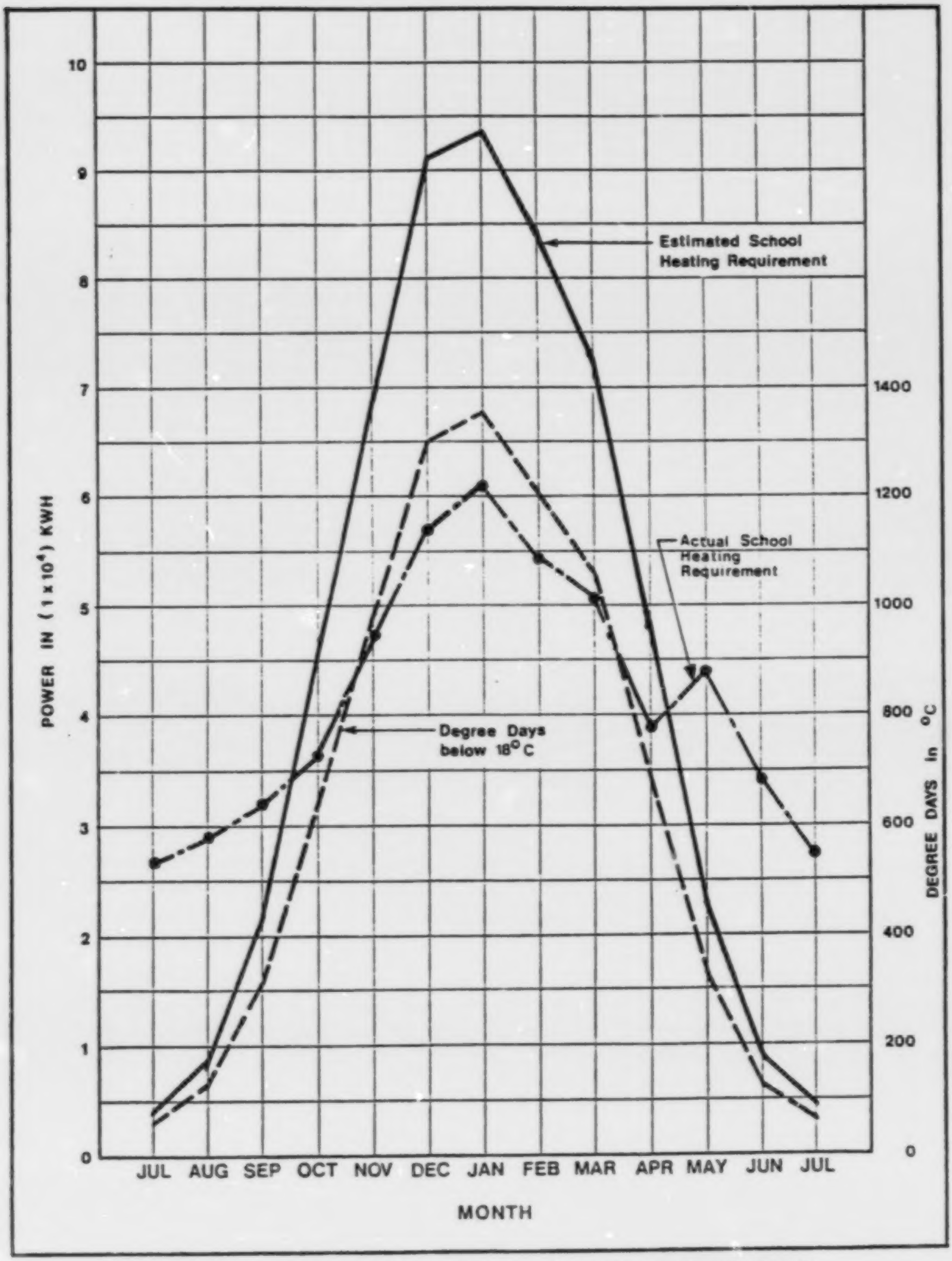
RELATIONSHIP BETWEEN NCPC GENERATOR OUTPUT and ITS SUBSEQUENT HEAT OUTPUT

GRAPH 2



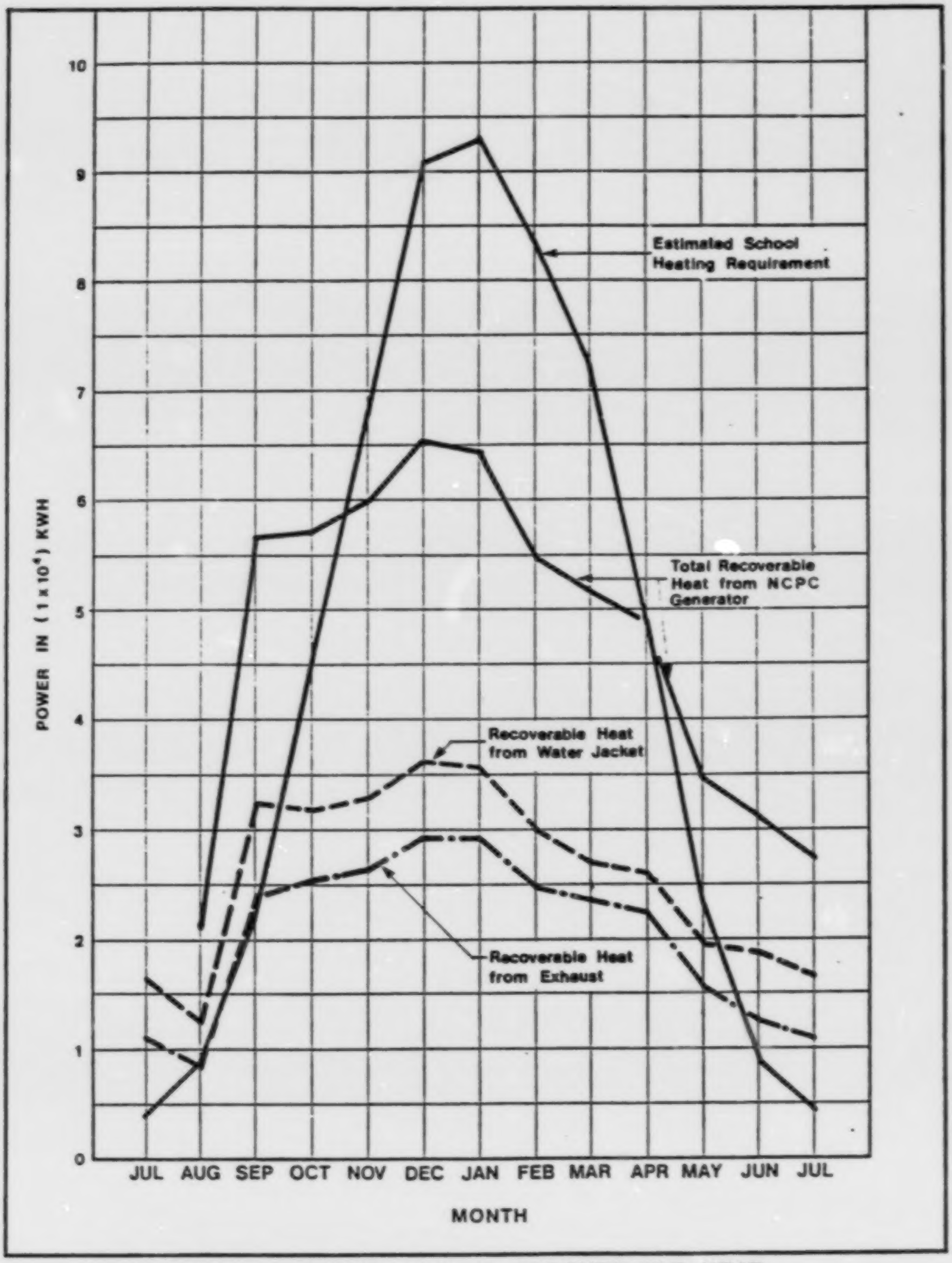
RELATIONSHIP BETWEEN GENERATOR HEAT PRODUCTION and RECOVERABLE HEAT (Estimated)

GRAPH 3



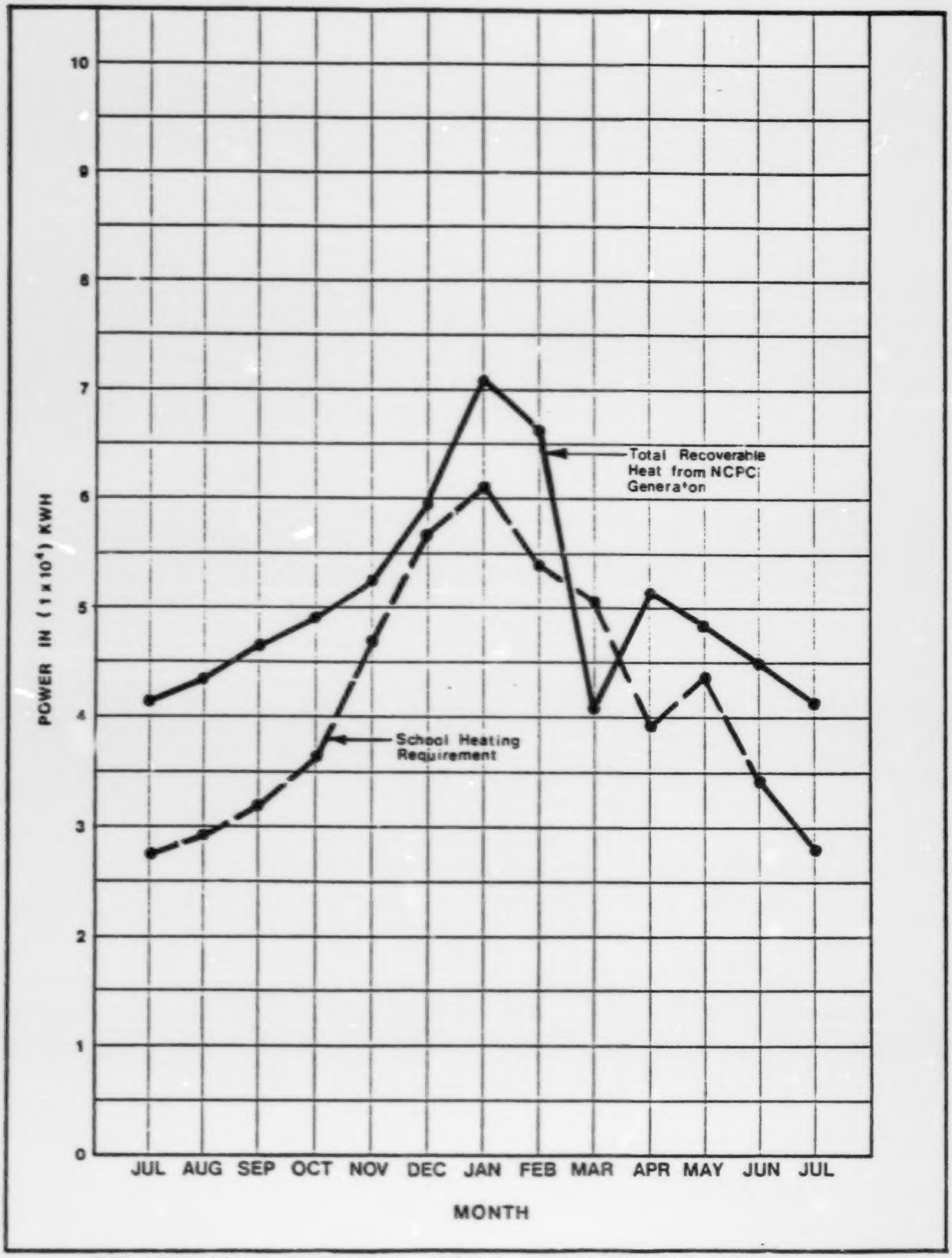
RELATIONSHIP BETWEEN LAC LA MARTRE DEGREE DAYS and SCHOOL HEATING REQUIREMENT

GRAPH 4



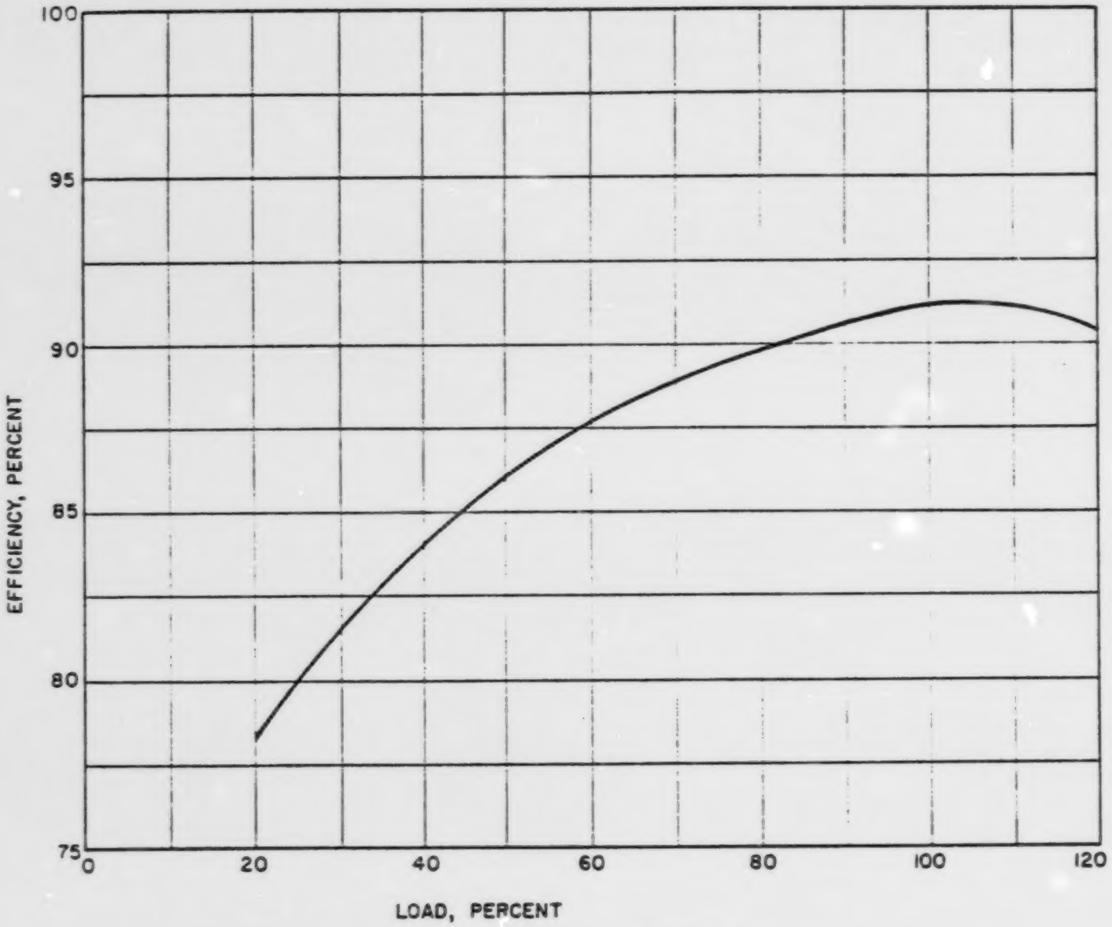
RELATIONSHIP BETWEEN NCPC RECOVERABLE HEAT and SCHOOL HEATING REQUIREMENT (Original Design Estimate)

GRAPH 5



RELATIONSHIP BETWEEN NCPC RECOVERABLE HEAT and SCHOOL HEATING REQUIREMENT (Actual)

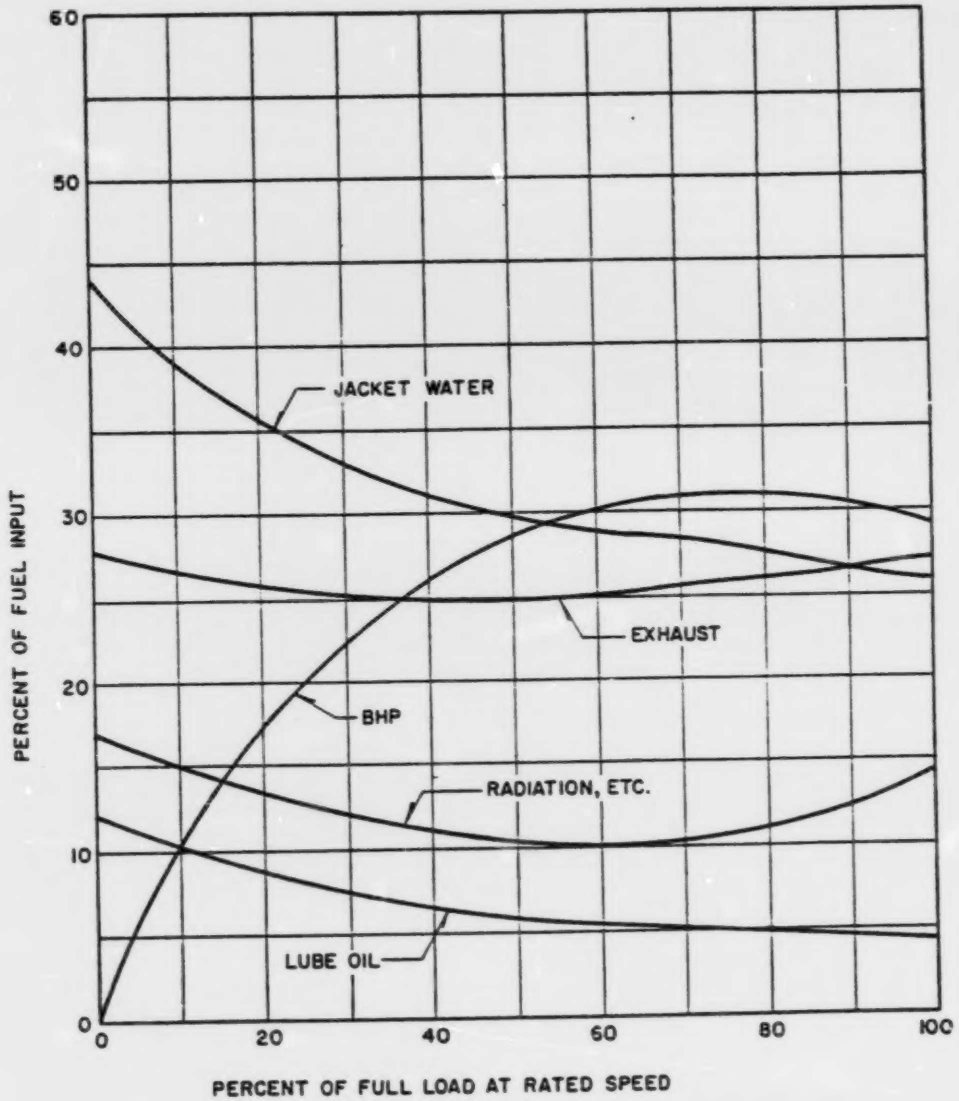
GRAPH 6



TYPICAL GENERATOR EFFICIENCY

BASED ON ASHRAE SYSTEMS 1976 BY PERMISSION

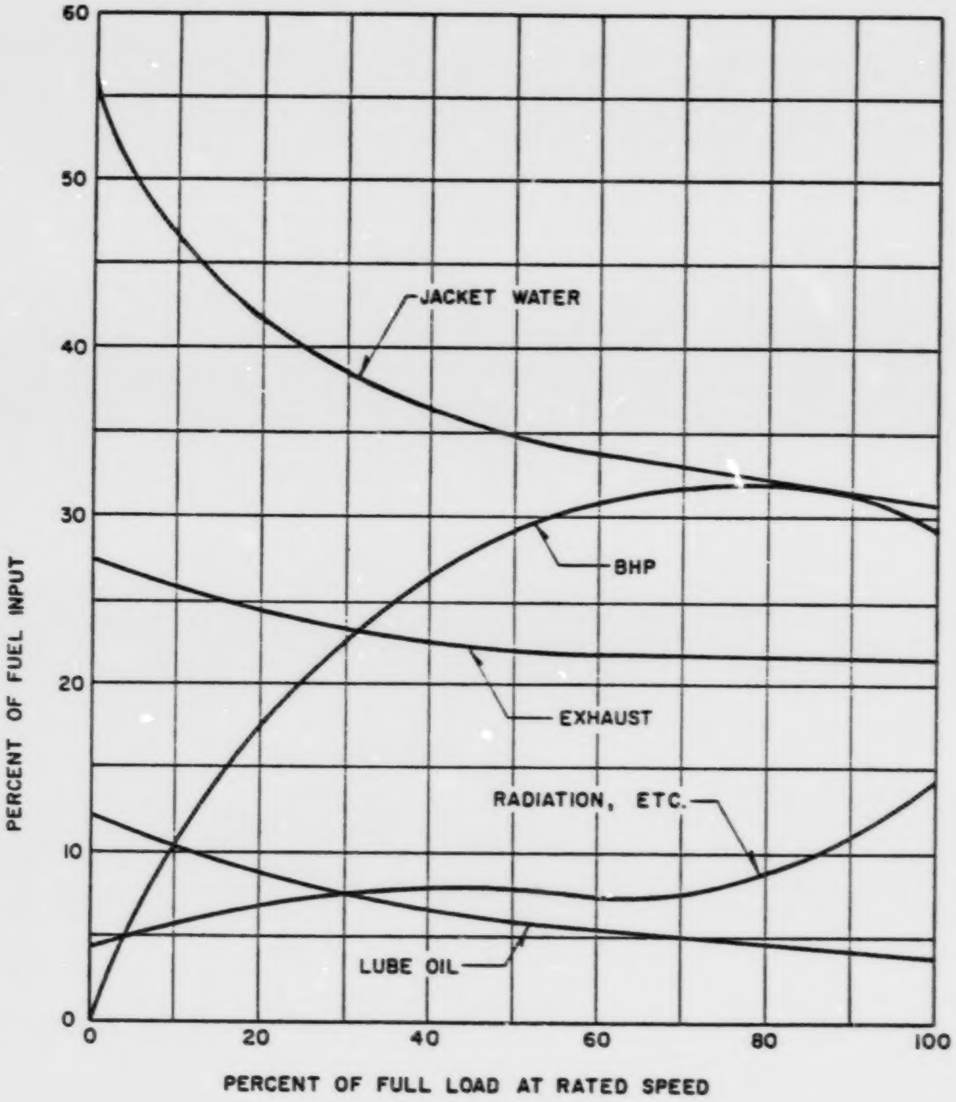
GRAPH 1A



HEAT BALANCE FOR TYPICAL UNSUPERCHARGED ENGINE WITH HOT EXHAUST MANIFOLD

BASED ON ASHRAE SYSTEMS 1976 BY PERMISSION

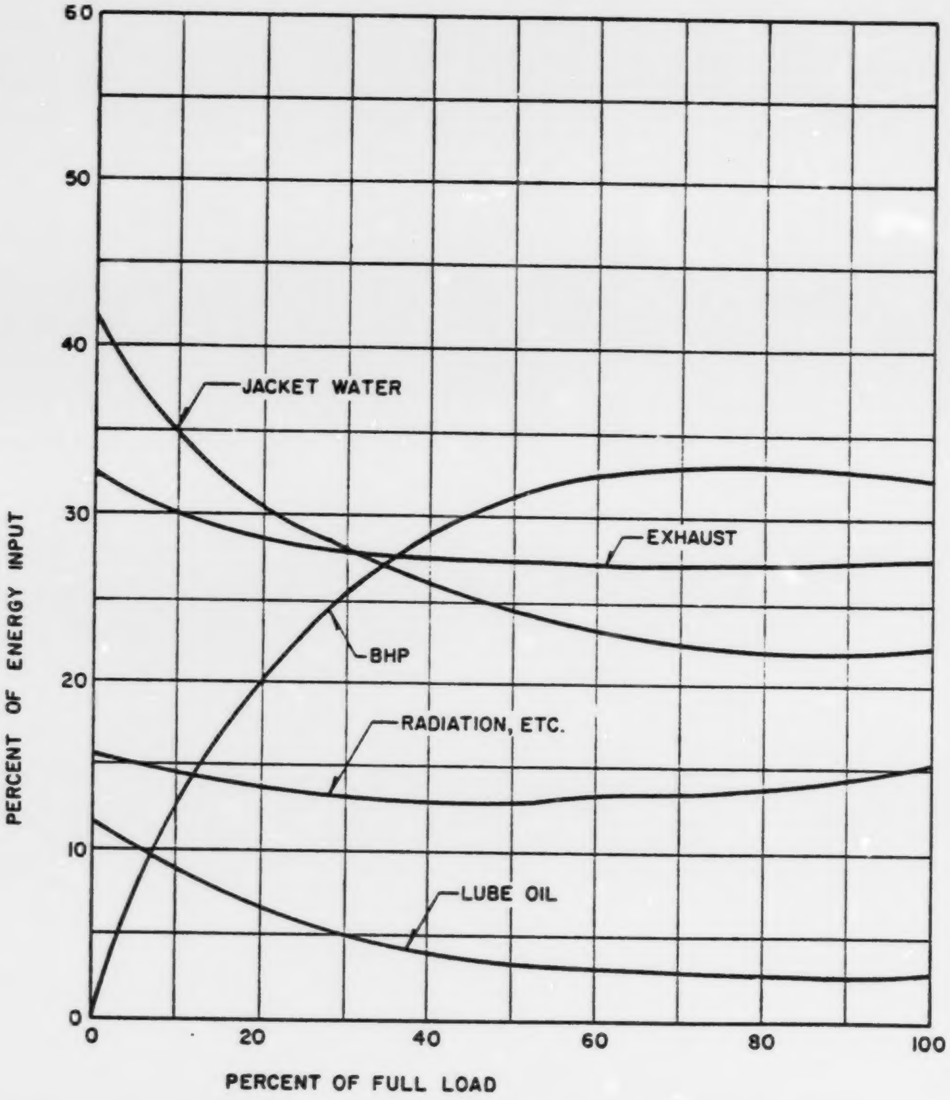
GRAPH 2A



HEAT BALANCE FOR TYPICAL UNSUPERCHARGED ENGINE WITH WATER-COOLED EXHAUST MANIFOLD

BASED ON ASHRAE SYSTEM 1976 BY PERMISSION

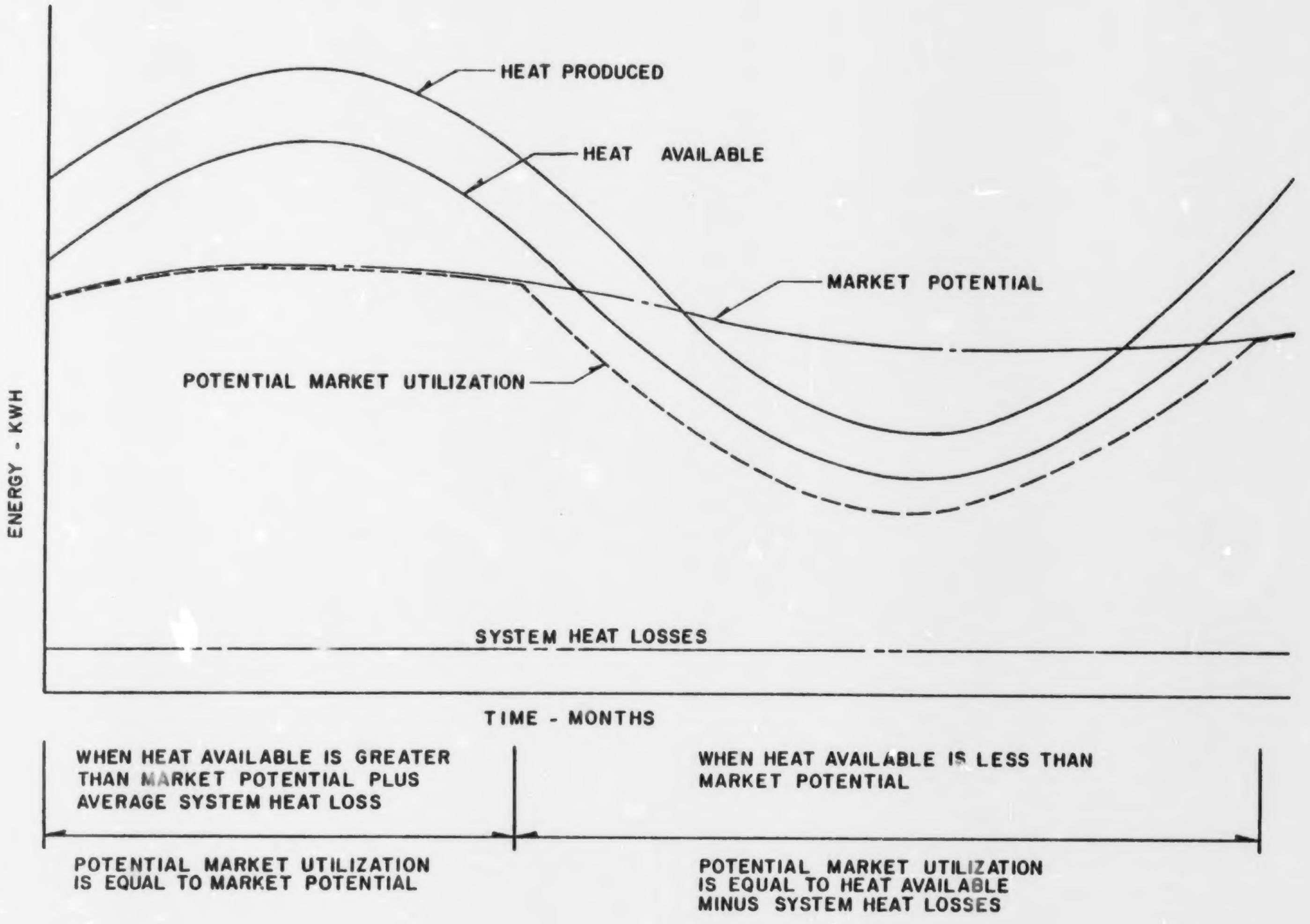
GRAPH 3A



HEAT BALANCE FOR TYPICAL TURBOCHARGED ENGINE

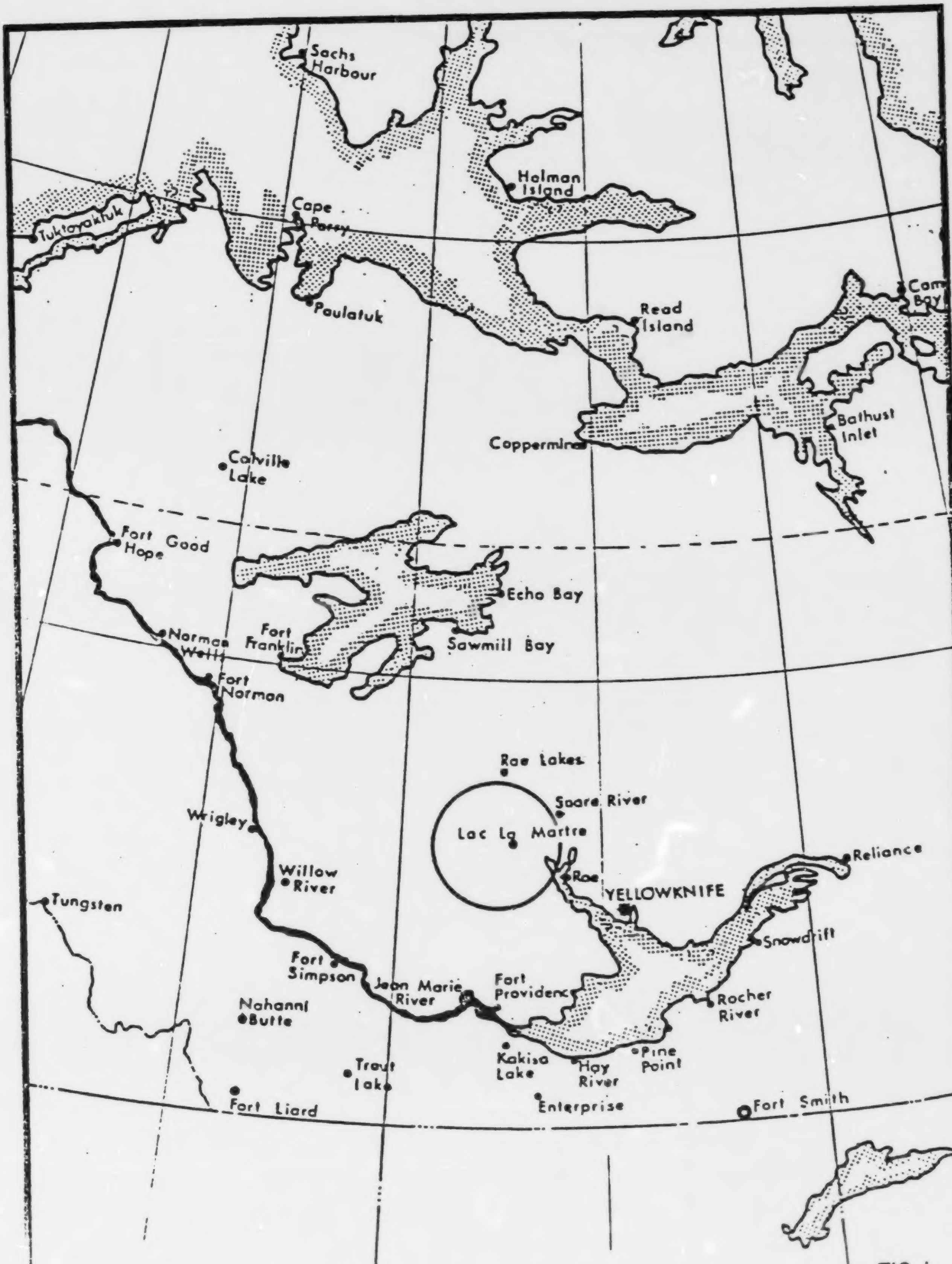
BASED ON ASHRAE 1976 SYSTEMS BY PERMISSION

GRAPH 4A



GRAPH 5A

HEAT AND MARKET RELATIONSHIPS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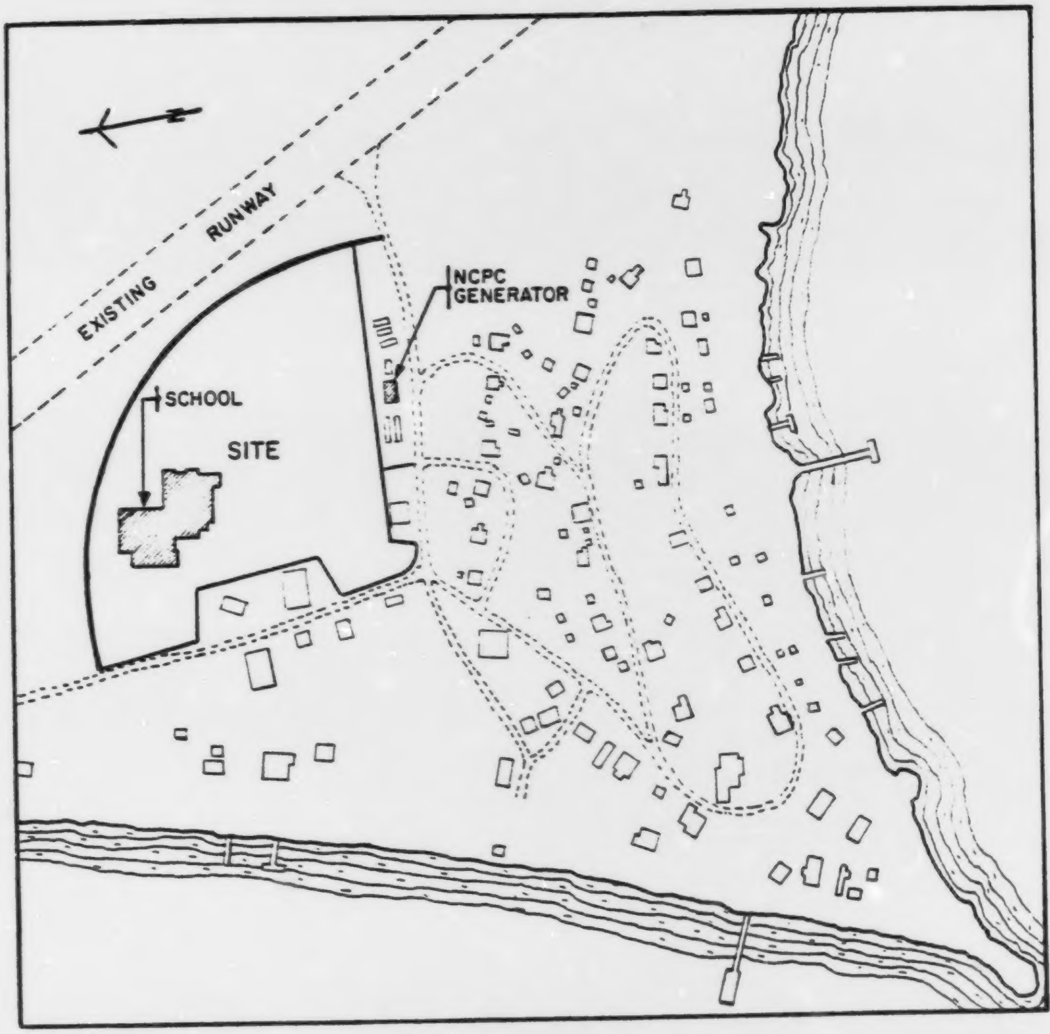
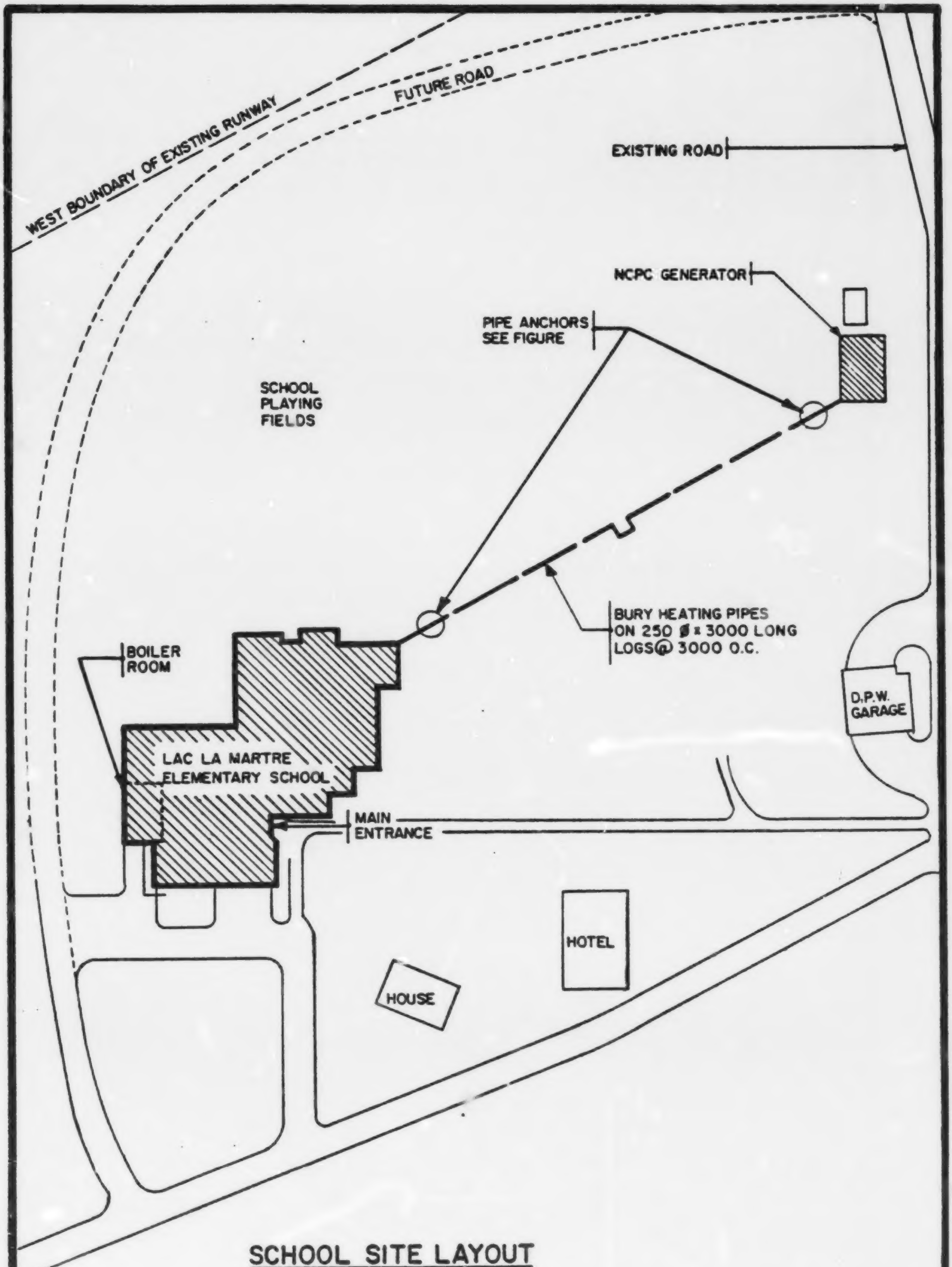
Holman Island
Tuktoyaktuk
Cape Parry
Paulatuk
Cam Bay
Read Island
Bathust Inlet
Coppermine
Colville Lake
Fort Good Hope
Echo Bay
Fort Franklin
Sawmill Bay
Norman Wells
Fort Norman
Rae Lakes
Snare River
Lac La Martre
Rae
Reliance
YELLOWKNIFE
Wrigley
Willow River
Tungsten
Snowdrift
Fort Simpson
Jean Marie River
Fort Providence
Rocher River
Nahanni Butte
Kakisa Lake
Hay River
Pine Point
Trout Lake
Fort Liard
Enterprise
Fort Smith

FIG. I


N
EXISTING RUNWAY
NCPC GENERATOR
SCHOOL
SITE

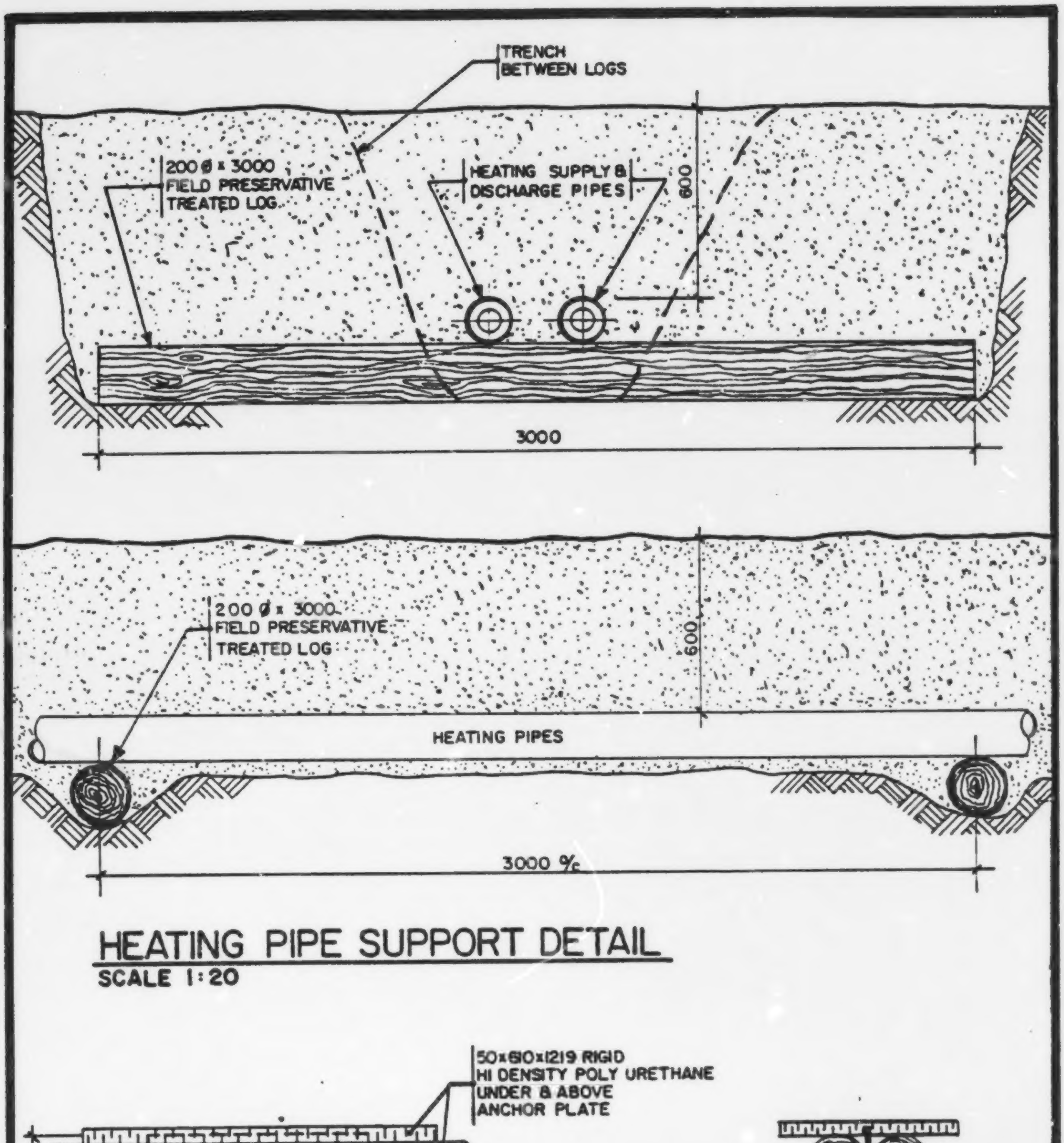
LOCATION MAP

FIG. 2

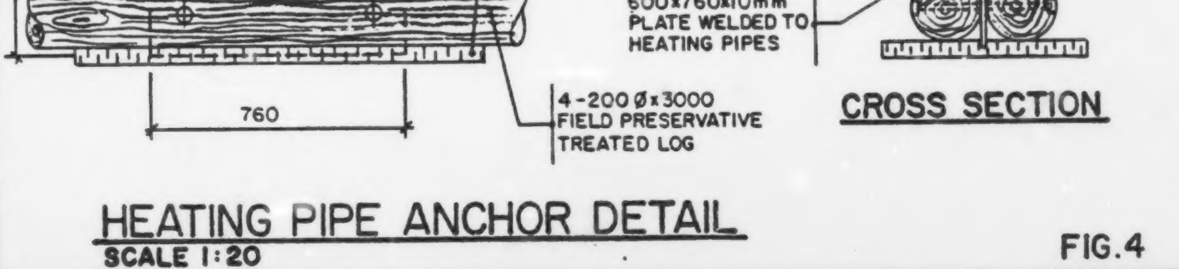

WEST BOUNDARY OF EXISTING RUNWAY
FUTURE ROAD
EXISTING ROAD
NCPC GENERATOR
PIPE ANCHORS SEE FIGURE
SCHOOL PLAYING FIELDS
BURY HEATING PIPES ON 250 Ø x 3000 LONG LOGS @ 3000 O.C.
BOILER ROOM
LAC LA MARTRE ELEMENTARY SCHOOL
MAIN ENTRANCE
D.P.W. GARAGE
HOTEL
HOUSE

SCHOOL SITE LAYOUT
SCALE 1:1000

FIG. 3


TRENCH
BETWEEN LOGS
200 Ø x 3000
FIELD PRESERVATIVE
TREATED LOG
HEATING SUPPLY &
DISCHARGE PIPES
600
3000
200 Ø x 3000
FIELD PRESERVATIVE
TREATED LOG
600
HEATING PIPES
3000 %

HEATING PIPE SUPPORT DETAIL
SCALE 1:20


50x610x1219 RIGID
HI DENSITY POLY URETHANE
UNDER & ABOVE
ANCHOR PLATE
600
100
TYP
760
4-200 Ø x 3000
FIELD PRESERVATIVE
TREATED LOG
HEATING
PIPES
600x760x10mm
PLATE WELDED TO
HEATING PIPES
CROSS SECTION

HEATING PIPE ANCHOR DETAIL
SCALE 1:20

FIG.4

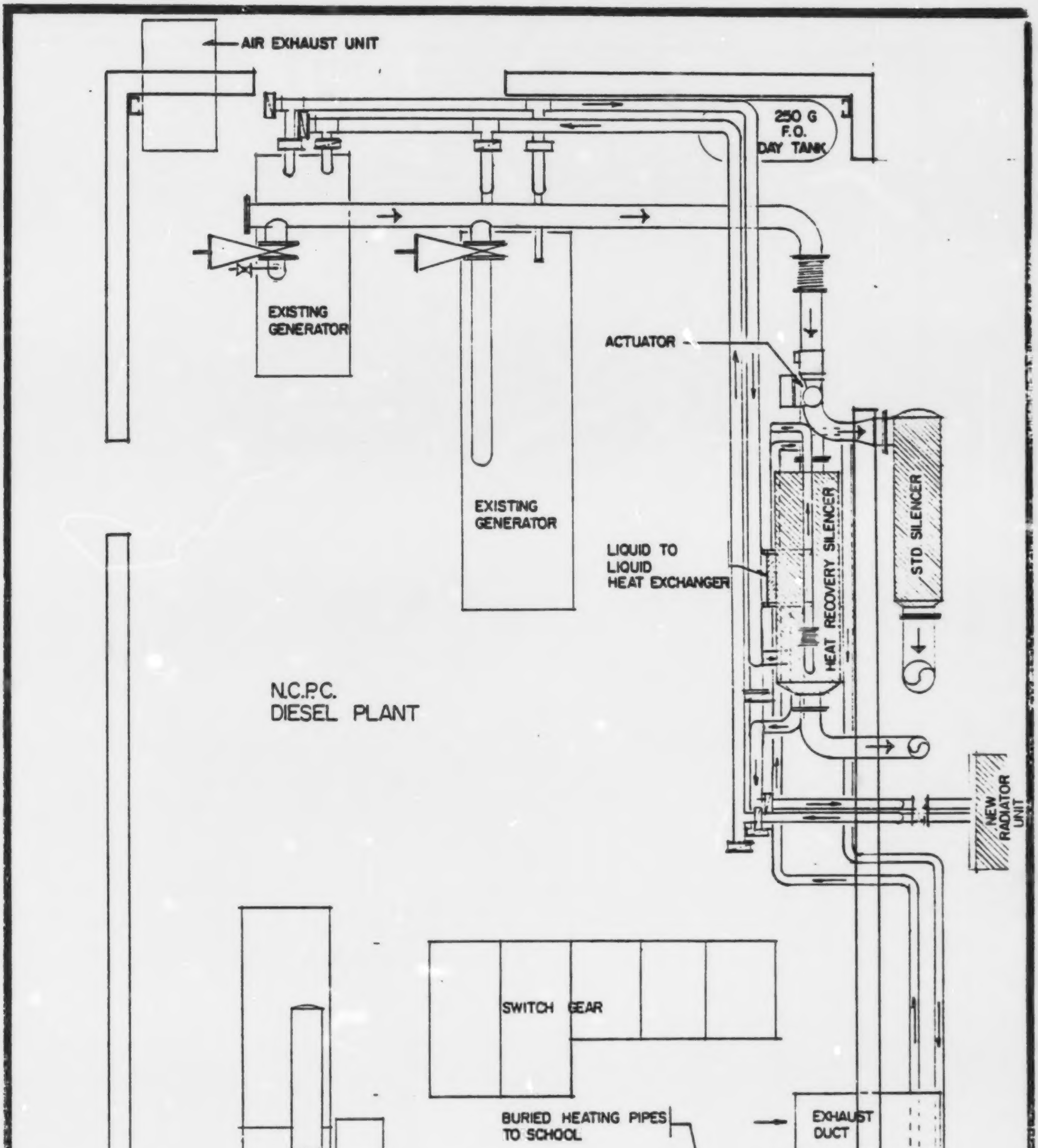
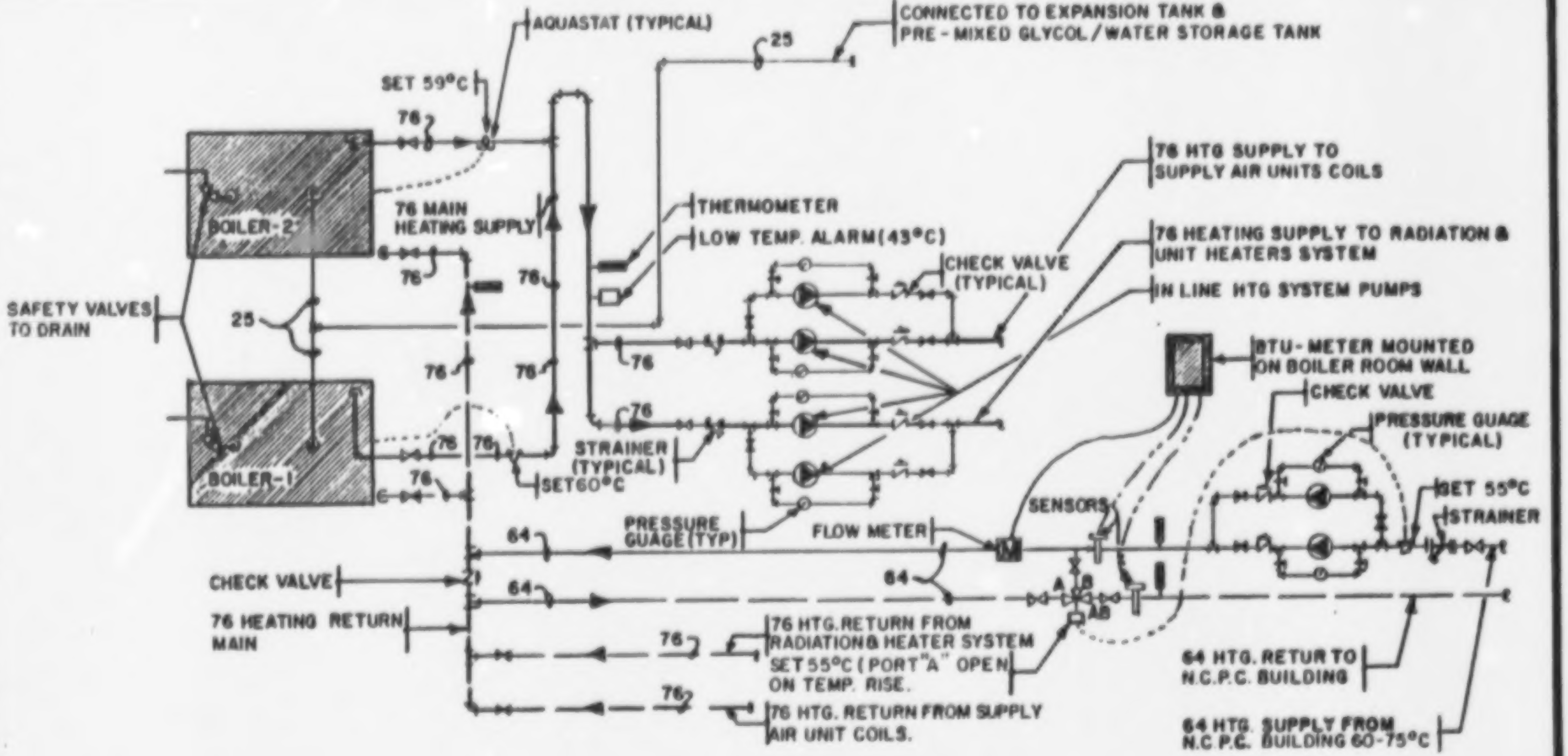
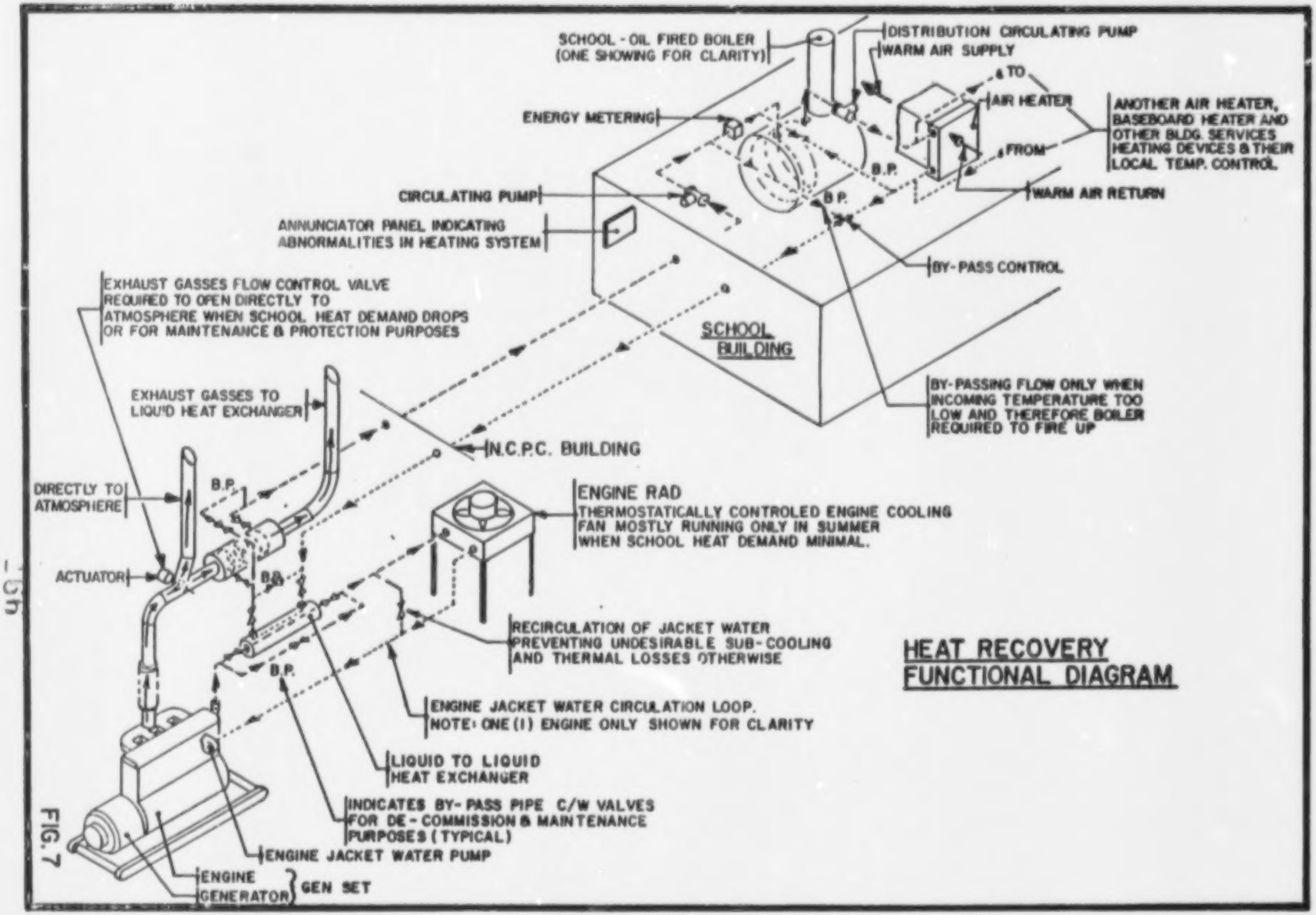

AIR EXHAUST UNIT
250 G F.O. DAY TANK
EXISTING GENERATOR
EXISTING GENERATOR
ACTUATOR
HEAT RECOVERY SILENCER
STD SILENCER
LIQUID TO LIQUID HEAT EXCHANGER
N.C.P.C. DIESEL PLANT
NEW RADIATOR UNIT
SWITCH GEAR
BURIED HEATING PIPES TO SCHOOL
EXHAUST DUCT
NEW AIR INTAKE

FIG. 5


AQUASTAT (TYPICAL)
25
CONNECTED TO EXPANSION TANK &
PRE-MIXED GLYCOL/WATER STORAGE TANK
SET 59°C
76
BOILER-2
BOILER-1
76 MAIN
HEATING SUPPLY
THERMOMETER
LOW TEMP. ALARM (43°C)
76 HTG SUPPLY TO
SUPPLY AIR UNITS COILS
76 HEATING SUPPLY TO RADIATION &
UNIT HEATERS SYSTEM
CHECK VALVE
(TYPICAL)
IN LINE HTG SYSTEM PUMPS
SAFETY VALVES
TO DRAIN
25
76
BTU-METER MOUNTED
ON BOILER ROOM WALL
CHECK VALVE
PRESSURE GUAGE
(TYPICAL)
STRAINER
(TYPICAL)
SET60°C
SENSORS
SET 55°C
STRAINER
PRESSURE
GUAGE(TYP)
FLOW METER
64
CHECK VALVE
A
B
AB
76 HEATING RETURN
MAIN
76 HTG. RETURN FROM
RADIATION & HEATER SYSTEM
SET 55°C (PORT "A" OPEN
ON TEMP. RISE.
64 HTG. RETUR TO
N.C.P.C. BUILDING
76 HTG. RETURN FROM SUPPLY
AIR UNIT COILS.
64 HTG. SUPPLY FROM
N.C.P.C. BUILDING 60-75°C

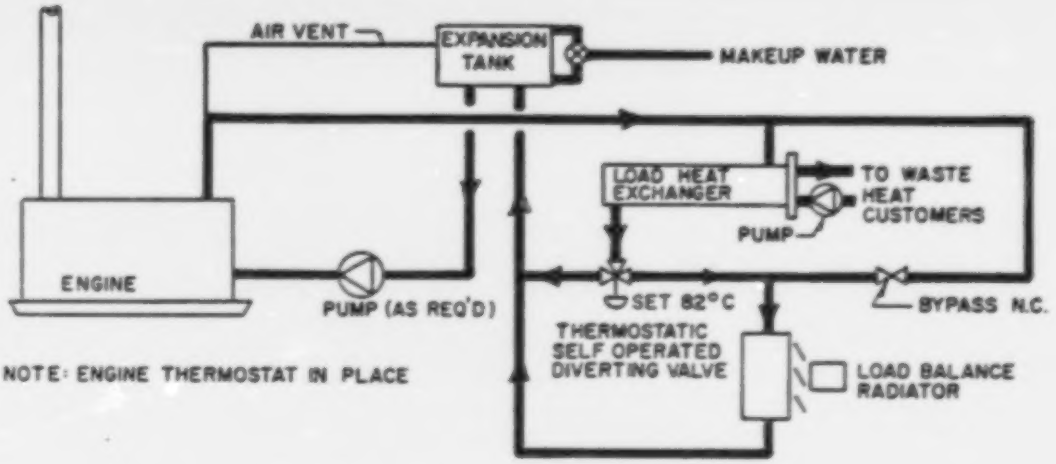
SCHOOL HEATING SYSTEM SCHEMATIC

FIG.6


SCHOOL - OIL FIRED BOILER (ONE SHOWING FOR CLARITY)
DISTRIBUTION CIRCULATING PUMP
WARM AIR SUPPLY
TO
AIR HEATER
FROM
ANOTHER AIR HEATER, BASEBOARD HEATER AND OTHER BLDG. SERVICES HEATING DEVICES & THEIR LOCAL TEMP. CONTROL
WARM AIR RETURN
ENERGY METERING
B.P.
CIRCULATING PUMP
B.P.
ANNUNCIATOR PANEL INDICATING ABNORMALITIES IN HEATING SYSTEM
BY-PASS CONTROL
EXHAUST GASSES FLOW CONTROL VALVE REQUIRED TO OPEN DIRECTLY TO ATMOSPHERE WHEN SCHOOL HEAT DEMAND DROPS OR FOR MAINTENANCE & PROTECTION PURPOSES
SCHOOL BUILDING
BY-PASSING FLOW ONLY WHEN INCOMING TEMPERATURE TOO LOW AND THEREFORE BOILER REQUIRED TO FIRE UP
EXHAUST GASSES TO LIQUID HEAT EXCHANGER
N.C.P.C. BUILDING
DIRECTLY TO ATMOSPHERE
B.P.
ENGINE RAD
THERMOSTATICALLY CONTROLED ENGINE COOLING FAN MOSTLY RUNNING ONLY IN SUMMER WHEN SCHOOL HEAT DEMAND MINIMAL.
ACTUATOR
B.P.
RECIRCULATION OF JACKET WATER PREVENTING UNDESIRABLE SUB-COOLING AND THERMAL LOSSES OTHERWISE
B.P.
ENGINE JACKET WATER CIRCULATION LOOP. NOTE: ONE (I) ENGINE ONLY SHOWN FOR CLARITY
LIQUID TO LIQUID HEAT EXCHANGER
INDICATES BY-PASS PIPE C/W VALVES FOR DE-COMMISSION & MAINTENANCE PURPOSES (TYPICAL)
ENGINE JACKET WATER PUMP
ENGINE
GENERATOR
GEN SET

HEAT RECOVERY
FUNCTIONAL DIAGRAM

FIG. 7

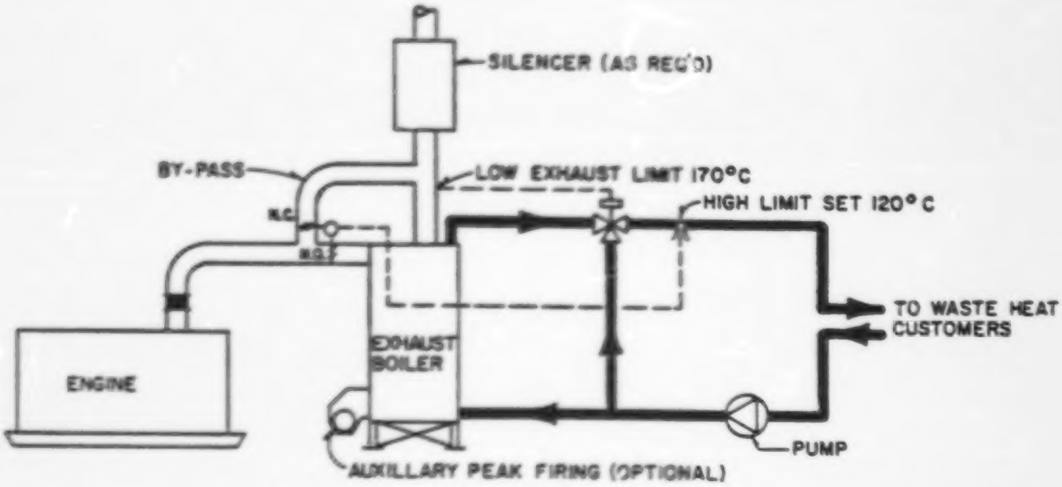

AIR VENT
EXPANSION TANK
MAKEUP WATER
LOAD HEAT EXCHANGER
TO WASTE HEAT CUSTOMERS
PUMP
ENGINE
PUMP (AS REQ'D)
SET 82°C
BYPASS N.C.
THERMOSTATIC SELF OPERATED DIVERTING VALVE
LOAD BALANCE RADIATOR
NOTE: ENGINE THERMOSTAT IN PLACE

SOLID WATER SYSTEM
JACKET RECOVERY ONLY

OPERATIONS:

THE ENGINE THERMOSTAT CONTROLS COOLANT FLOW IN THE LOOP. HEAT REJECTION TAKES PLACE IN THE LOAD HEAT EXCHANGER DEPENDING ON WASTE HEAT CUSTOMERS DEMANDS. WHEN THE LEAVING WATER TEMPERATURE FROM THE LOAD HEAT EXCHANGER IS LESS THAN 82°C, FLOW IS DIVERTED BACK TO THE ENGINE. FOR TEMPERATURES GREATER THAN 82°C, WATER DIVERSION IS TO THE LOAD BALANCE RADIATOR.

FIG. 1A


SILENCER (AS REQ'D)
BY-PASS
LOW EXHAUST LIMIT 170°C
HIGH LIMIT SET 120° C
N.C.
N.O.
TO WASTE HEAT CUSTOMERS
EXHAUST BOILER
ENGINE
PUMP
AUXILLARY PEAK FIRING (OPTIONAL)

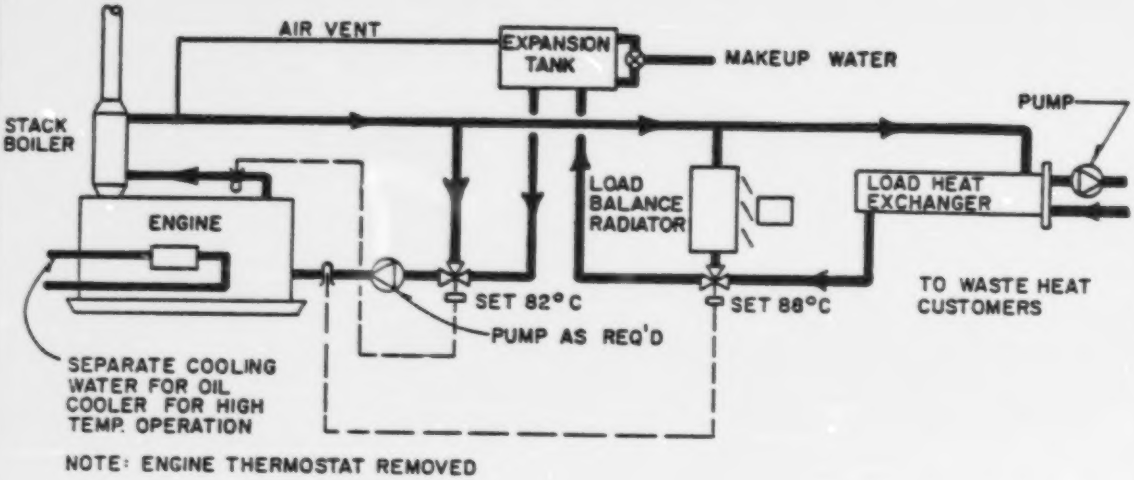
SOLID WATER SYSTEM
EXHAUST RECOVERY ONLY

OPERATION:

FLOW THROUGH THE EXHAUST BOILER IS GOVERNED BY THE LOW EXHAUST TEMPERATURE CONTROL SET ABOVE THE CONDENSATION TEMPERATURE OF THE GAS. TEMPERATURES BELOW 170°C WILL CAUSE THE THREE WAY VALVE TO BY-PASS THE BOILER TO REDUCE THE AMOUNT OF HEAT EXTRACTED. ABOVE 170°C, FULL FLOW IS THROUGH THE BOILER. WHEN CUSTOMER DEMAND IS LOW, THE HIGH LIMIT SET AT 120°C WILL BY-PASS EXHAUST GAS.

AUXILLARY PEAK FIRING IS SET TO OPERATE AT A MINIMUM SUPPLY WATER TEMPERATURE AND USUALLY ELIMINATES THE NEED FOR THE LOW EXHAUST LIMIT.

FIG. 2A

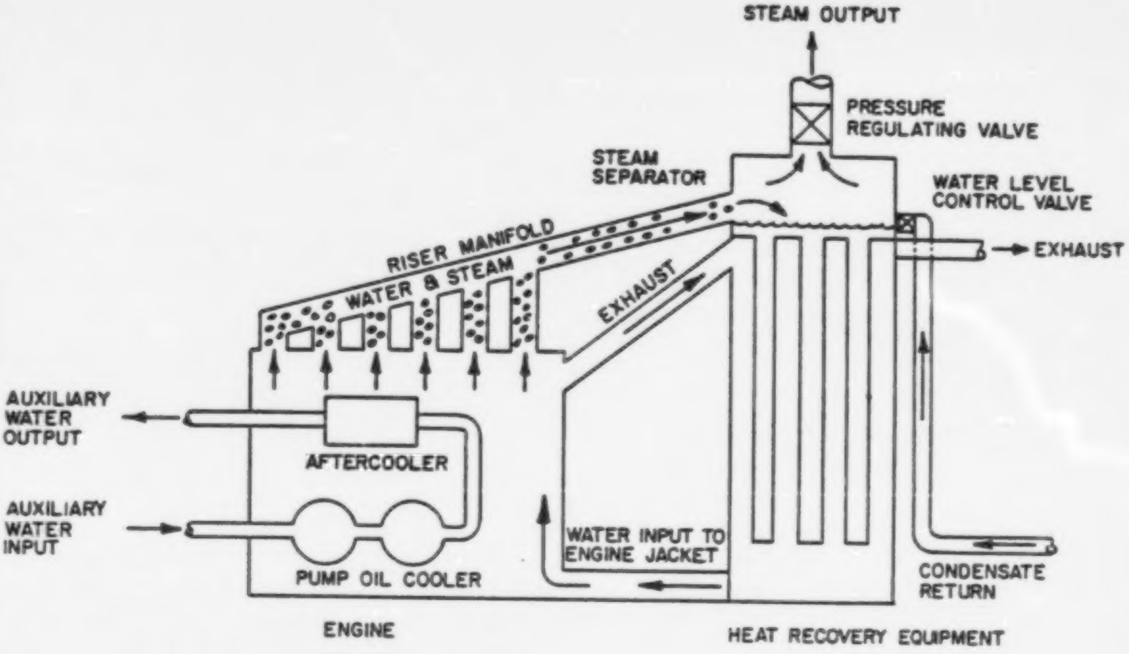

AIR VENT
EXPANSION TANK
MAKEUP WATER
PUMP
STACK BOILER
ENGINE
LOAD BALANCE RADIATOR
LOAD HEAT EXCHANGER
SET 82° C
SET 88°C
PUMP AS REQ'D
TO WASTE HEAT CUSTOMERS
SEPARATE COOLING WATER FOR OIL COOLER FOR HIGH TEMP. OPERATION
NOTE: ENGINE THERMOSTAT REMOVED

SOLID WATER SYSTEM
JACKET AND STACK RECOVERY

OPERATION:

TO PREVENT THERMAL SHOCK, FULL FLOW IS MAINTAINED THROUGH THE STACK BOILER BY REMOVING THE ENGINE THERMOSTAT. MINIMUM ENGINE TEMPERATURE IS MAINTAINED THROUGH THE THREE-WAY VALVE SET TO 82°C. IN CASES WHERE THE LOAD HEAT EXCHANGER DOES NOT ABSORB THE FULL ENGINE OUTPUT, THE THREE WAY VALVE SET TO 88°C WILL BLEND WATER THROUGH THE LOAD BALANCE RADIATOR UNTIL THE ENGINE RETURN WATER IS BELOW 88°C.

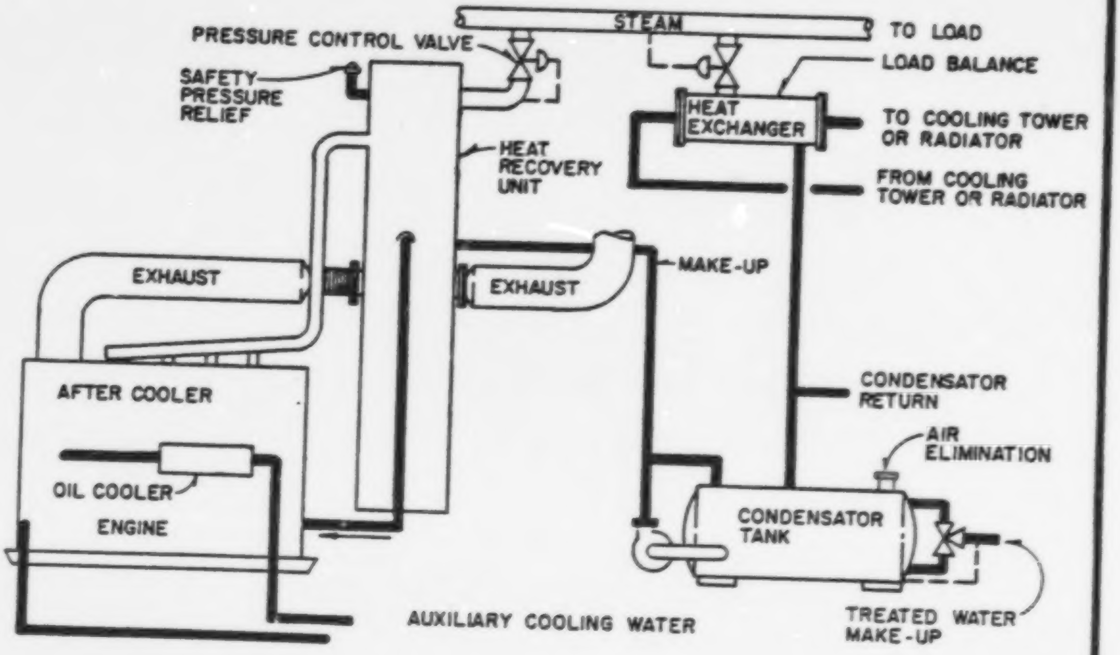
FIG. 3A


STEAM OUTPUT
PRESSURE REGULATING VALVE
STEAM SEPARATOR
WATER LEVEL CONTROL VALVE
EXHAUST
RISER MANIFOLD
WATER & STEAM
EXHAUST
AUXILIARY WATER OUTPUT
AFTERCOOLER
AUXILIARY WATER INPUT
WATER INPUT TO ENGINE JACKET
PUMP OIL COOLER
CONDENSATE RETURN
ENGINE
HEAT RECOVERY EQUIPMENT

THE EBULLIENT SYSTEM

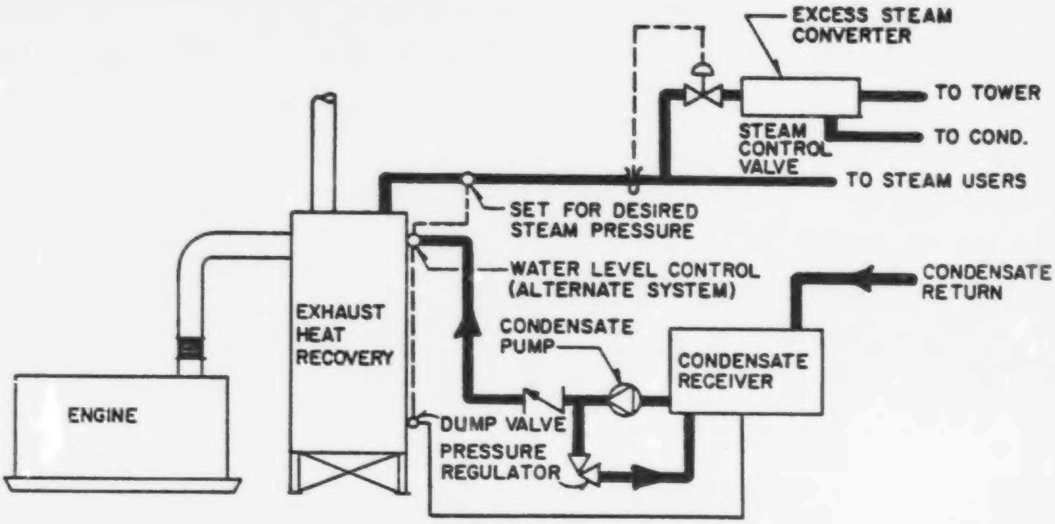
OPERATION OF THE EBULLIENT SYSTEM IS DESCRIBED IN SECTION 6.2.4 AND APPENDIX A.4

FIG. 4A


STEAM
TO LOAD
PRESSURE CONTROL VALVE
LOAD BALANCE
SAFETY PRESSURE RELIEF
HEAT EXCHANGER
TO COOLING TOWER OR RADIATOR
HEAT RECOVERY UNIT
FROM COOLING TOWER OR RADIATOR
MAKE-UP
EXHAUST
EXHAUST
AFTER COOLER
CONDENSATOR RETURN
AIR ELIMINATION
CONDENSATOR TANK
OIL COOLER
ENGINE
AUXILIARY COOLING WATER
TREATED WATER MAKE-UP

EBULLIENT SYSTEM SCHEMATIC

FIG. 5A


EXCESS STEAM CONVERTER
TO TOWER
STEAM CONTROL VALVE
TO COND.
TO STEAM USERS
SET FOR DESIRED STEAM PRESSURE
WATER LEVEL CONTROL (ALTERNATE SYSTEM)
CONDENSATE RETURN
EXHAUST HEAT RECOVERY
CONDENSATE PUMP
CONDENSATE RECEIVER
ENGINE
DUMP VALVE
PRESSURE REGULATOR

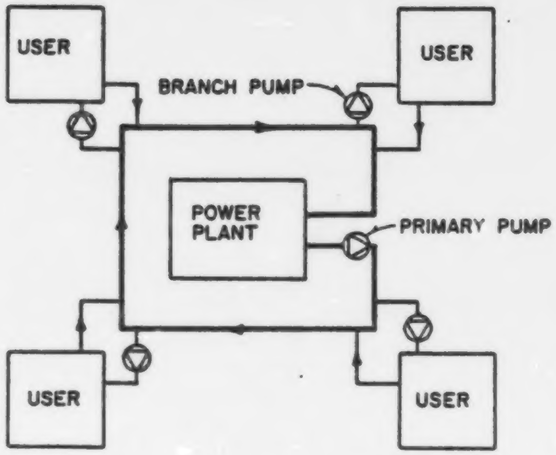
EXHAUST HEAT RECOVERY - STEAM

OPERATION:

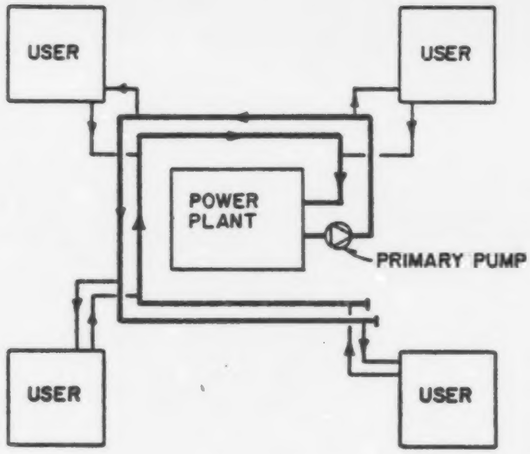
BACKPRESSURE ON THE EXHAUST RECOVERY IS CONTROLLED BY THE STEAM VALVE. DURING PERIODS OF LOW CUSTOMER USE, EXCESS STEAM CAN BE ABSORBED BY THE EXCESS STEAM CONVERTER, OR ALTERNATELY, BY LOWERING THE LEVEL OF WATER IN THE EXHAUST BOILER TO REDUCE THE HEAT EXCHANGER SURFACE AREA.

THE WATER LEVEL CONTROL IS APPROVED ONLY FOR VERTICAL EXHAUST BOILERS, SO THAT EXCESS STEAM CONVERTERS ARE MANDATORY ON HORIZONTAL BOILERS.

FIG. 6A


USER
USER
BRANCH PUMP
POWER PLANT
PRIMARY PUMP
USER
USER

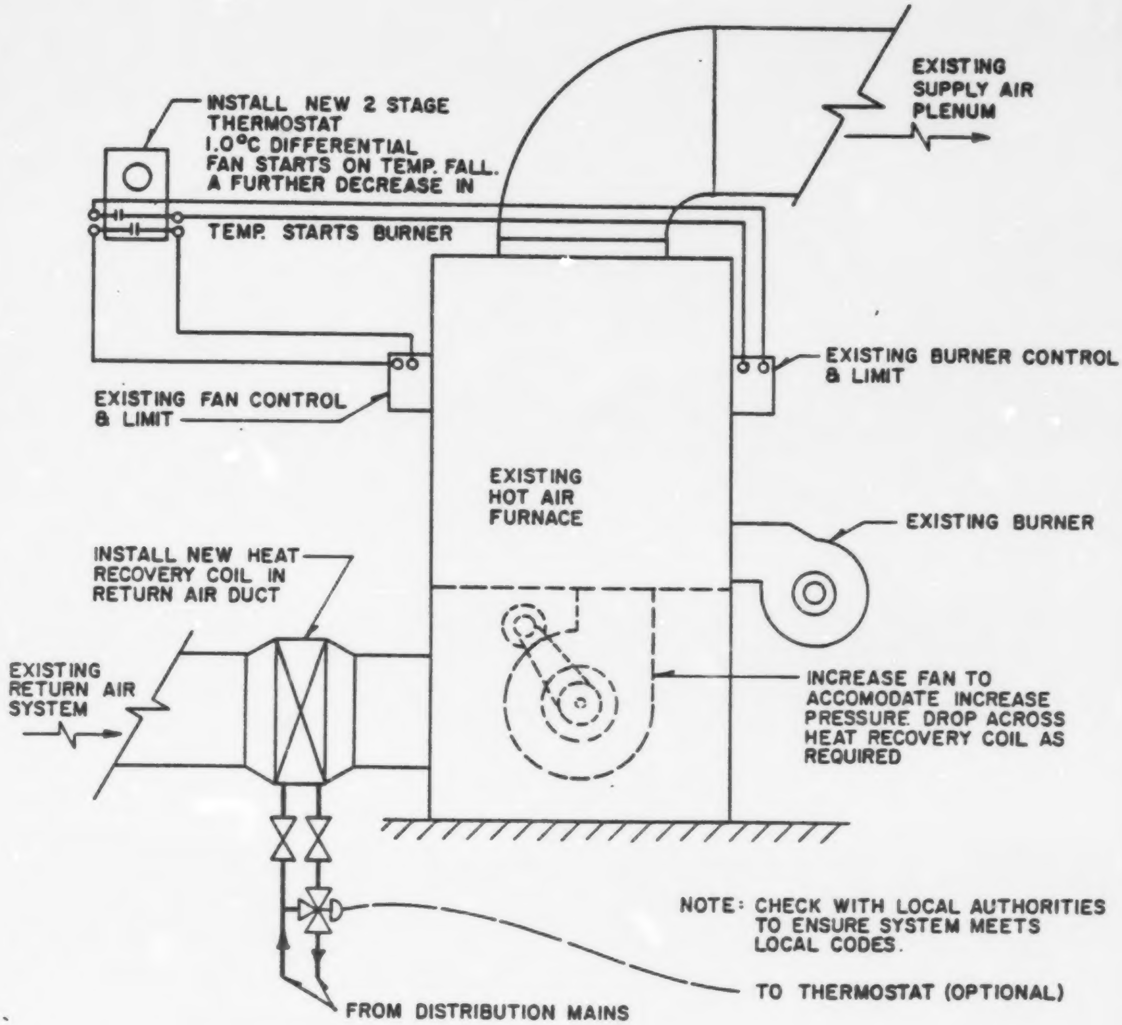
ONE PIPE DISTRIBUTION SYSTEM


USER
USER
POWER PLANT
PRIMARY PUMP
USER
USER

TWO PIPE DISTRIBUTION SYSTEM

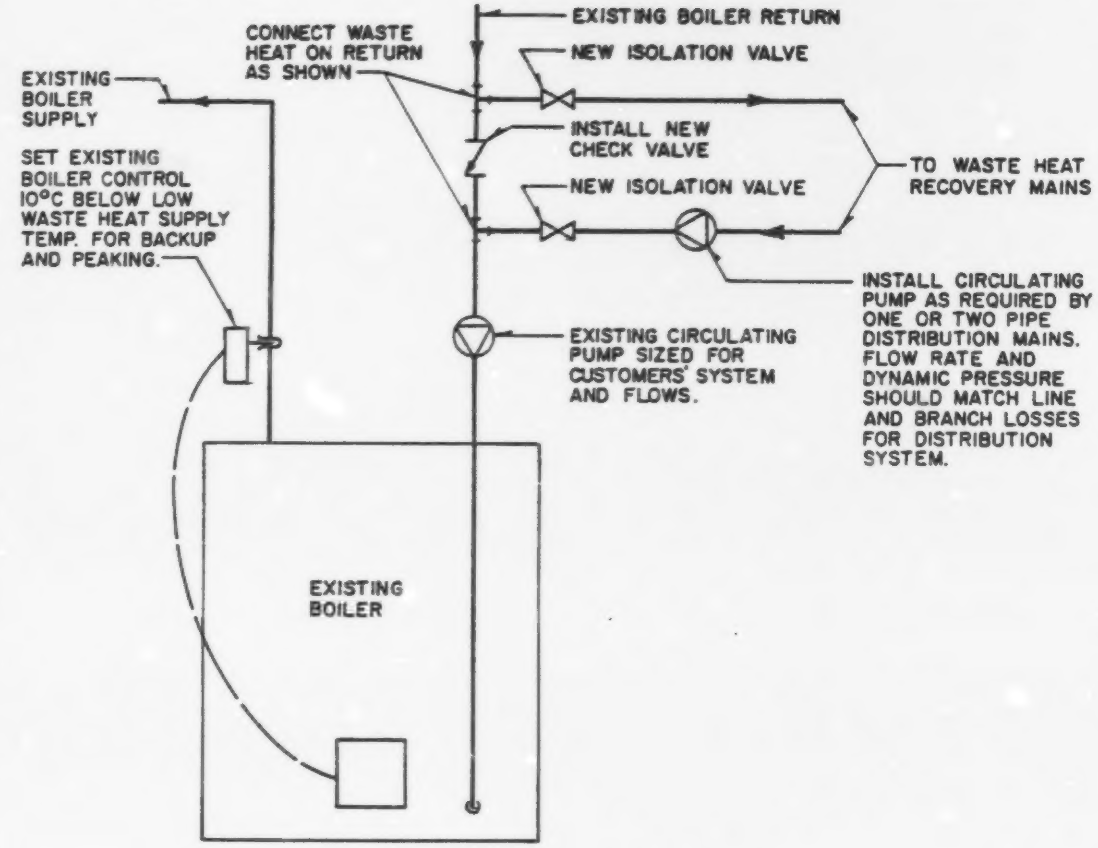
ONE AND TWO PIPE MAIN DISTRIBUTION ALTERNATIVES
SOLID WATER

FIG. 7A


INSTALL NEW 2 STAGE THERMOSTAT
1.0°C DIFFERENTIAL
FAN STARTS ON TEMP. FALL.
A FURTHER DECREASE IN
TEMP. STARTS BURNER
EXISTING SUPPLY AIR PLENUM
EXISTING BURNER CONTROL & LIMIT
EXISTING FAN CONTROL & LIMIT
EXISTING HOT AIR FURNACE
EXISTING BURNER
INSTALL NEW HEAT RECOVERY COIL IN RETURN AIR DUCT
EXISTING RETURN AIR SYSTEM
INCREASE FAN TO ACCOMODATE INCREASE PRESSURE DROP ACROSS HEAT RECOVERY COIL AS REQUIRED
NOTE: CHECK WITH LOCAL AUTHORITIES TO ENSURE SYSTEM MEETS LOCAL CODES.
TO THERMOSTAT (OPTIONAL)
FROM DISTRIBUTION MAINS

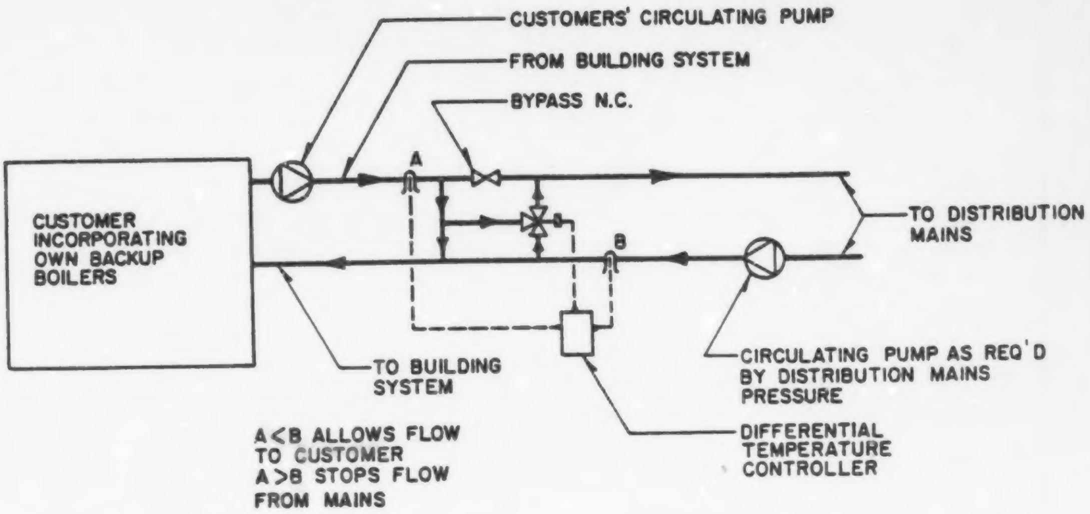
CONVERSION FOR HOT AIR SYSTEM, MAINTAINING EXISTING FURNACE AS BACKUP.

FIG. 8A


EXISTING BOILER RETURN
NEW ISOLATION VALVE
CONNECT WASTE HEAT ON RETURN AS SHOWN
EXISTING BOILER SUPPLY
INSTALL NEW CHECK VALVE
TO WASTE HEAT RECOVERY MAINS
SET EXISTING BOILER CONTROL 10°C BELOW LOW WASTE HEAT SUPPLY TEMP. FOR BACKUP AND PEAKING.
NEW ISOLATION VALVE
INSTALL CIRCULATING PUMP AS REQUIRED BY ONE OR TWO PIPE DISTRIBUTION MAINS. FLOW RATE AND DYNAMIC PRESSURE SHOULD MATCH LINE AND BRANCH LOSSES FOR DISTRIBUTION SYSTEM.
EXISTING CIRCULATING PUMP SIZED FOR CUSTOMERS' SYSTEM AND FLOWS.
EXISTING BOILER

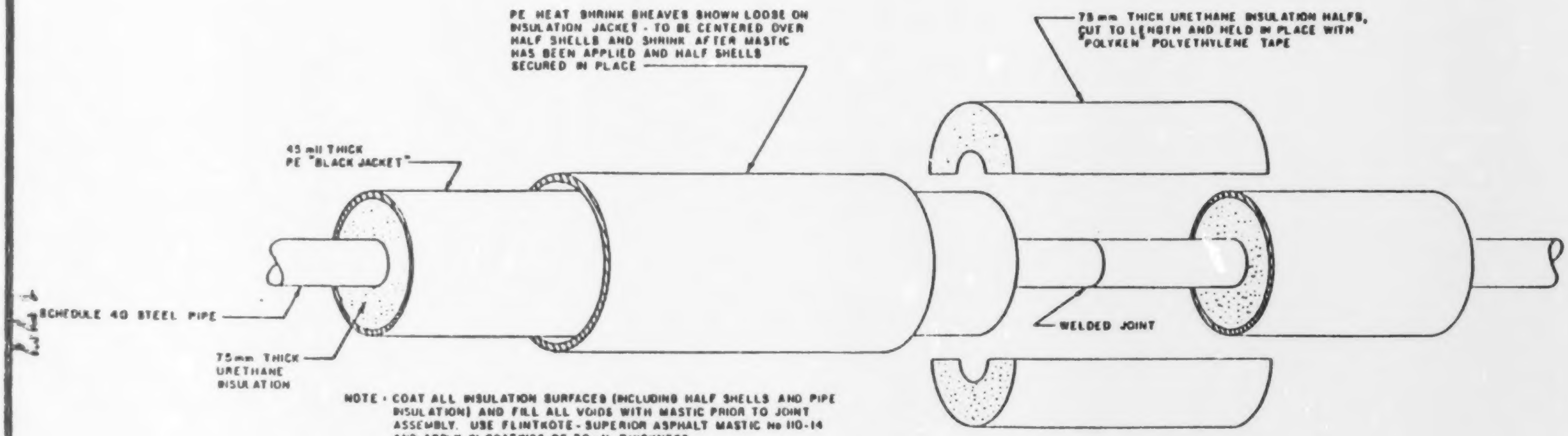
TYPICAL BOILER MODIFICATION TO WASTE HEAT RECOVERY

FIG. 9A


CUSTOMERS' CIRCULATING PUMP
FROM BUILDING SYSTEM
BYPASS N.C.
A
B
CUSTOMER INCORPORATING OWN BACKUP BOILERS
TO DISTRIBUTION MAINS
TO BUILDING SYSTEM
CIRCULATING PUMP AS REQ'D BY DISTRIBUTION MAINS PRESSURE
A<B ALLOWS FLOW TO CUSTOMER
A>B STOPS FLOW FROM MAINS
DIFFERENTIAL TEMPERATURE CONTROLLER

CONTROL ARRANGEMENT USED TO PREVENT CUSTOMER FROM SUPPYING HEAT TO MAIN DISTRIBUTION SYSTEM

FIG. 10A


PE HEAT SHRINK SHEAVES SHOWN LOOSE ON INSULATION JACKET - TO BE CENTERED OVER HALF SHELLS AND SHRINK AFTER MASTIC HAS BEEN APPLIED AND HALF SHELLS SECURED IN PLACE
75mm THICK URETHANE INSULATION HALFS, CUT TO LENGTH AND HELD IN PLACE WITH "POLYKEN" POLYETHYLENE TAPE
45 mil THICK PE "BLACK JACKET"
SCHEDULE 40 STEEL PIPE
75mm THICK URETHANE INSULATION
WELDED JOINT

NOTE - COAT ALL INSULATION SURFACES (INCLUDING HALF SHELLS AND PIPE INSULATION) AND FILL ALL VOIDS WITH MASTIC PRIOR TO JOINT ASSEMBLY. USE FLINTKOTE - SUPERIOR ASPHALT MASTIC No 110-14 AND APPLY IN COATINGS OF 30mil THICKNESS

DISTRIBUTION PIPING INSULATION METHOD

FIG. IIA

TABLE 1

LAC LA MARTRE HEAT RECOVERY STUDY

DATE	TIME	OUTSIDE AIR TEMP.(°C)	WATER SUPPLY TEMP. (°C) (RED BOTTON)	WATER RETURN TEMP.(°C) (BLUE BOTTON)	Δ T READING ON TEMP. DIAL	WATER FLOW M³	ENERGY MWh	OIL DAY TANK GUAGE (LITRES)
JAN 7	14-24	-24	65	49	16	13187·9	157·19	145·00
7	15-31	-24	65	52	13	13196·4	157·325	—"—
8	14-10	-20	67	52·5	14·5	13370·7	159·20	—"—
9	14-55	-29	66	52	14	13561·9	161·43	—"—
10	14-35	-34	61	49	12	13745·9	163·69	—"—
11	14-00	-32	61	48	13	13926·8	165·92	—"—
12	13-50	-30	62	50	12	14110·9	168·19	—"—
13	14-00	-26	65	51	14	14303·1	170·54	—"—
14	11-45	-26	76	72	4	14464·6	172·31	—"—
15	—	-25	—	—	—	—	—	—
16	15-00	-23	78	74	4	14873·3	174·83	145·00
17	9-15	-20	78	74	4	15016·5	175·91	—"—
18	14-00	-20	58	50	8	15243·6	178·38	—"—
19	15-00	-15	78	66	11	15438·1	180·43	—"—
20	10-00	-22	73	60	12	15585·6	181·97	—"—
21	10-00	-22	76	64	13	15768·5	184·00	—"—
22	—	-26	—	—	—	—	—	—
23	—	-30	—	—	—	—	—	—
24	10-40	-33	70	58	12	16341·4	190·98	145·00
25	10-00	-36	68	56	12	16526·1	192·96	—"—
26	9-00	-30	64	52	12	16688·5	194·69	—"—
27	9-00	-25	66	56	10	16880·6	196·85	—"—

TABLE 1.

LAC LA MARTRE HEAT RECOVERY STUDY

DATE	TIME	OUTSIDE AIR TEMP.(°C)	WATER SUPPLY TEMP. (°C) (RED BOTTON)	WATER RETURN TEMP.(°C) (BLUE BOTTON)	Δ T READING ON TEMP. DIAL	WATER FLOW M³	ENERGY MWh	OIL DAY TANK GUAGE (LITRES)
JAN 28	9.00	-25	76	68	9	17074.9	198.84	145.00
29	13.00	-18	70	54	14	17301.6	201.66	"
31	13.00	-32	60	48	12	17679.1	206.06	"
FEB 1	10.00	-37	68	58	10	17845.2	207.98	"
2	9.00	-38	72	60	12	18031.1	210.18	"
3	9.00	-38	60	50	10	18222.3	212.62	"
4	9.00	-37	64	52	12	18416.7	214.74	"
5	13.00	-38	60	50	10	18633.7	217.43	"
6	17.00	-38	60	50	10	18867.1	219.97	"
13	13.00	-23	70	62	8	20181.7	233.92	"
14	8.30	-20	68	58	10	20288.7	235.39	"
15	9.00	-28	70	60	10	20469.8	237.31	"
16	9.00	-30	65	54	11	20660.6	239.42	"
17	9.00	-34	65	52	12	20835.2	241.65	"
18	9.00	-28	72	62	10	21018.8	243.69	"
21	11.00	-15	75	64	11	21570.1	249.90	"
22	9.00	-12	70	58	12	21738.0	251.68	"
24	8.30	-12	60	62	2	22099.3	255.95	"
25	8.30	-6	66	58	8	22278.6	257.97	"
26	9.00	-30	66	70	8	22464.2	260.24	"
28	10.00	-23	76	68	24	22857.6	261.03	"

TABLE 1.

LAC LA MARTRE HEAT RECOVERY STUDY

DATE	TIME	OUTSIDE AIR TEMP. (°C)	WATER SUPPLY TEMP. (°C) (RED BOTTON)	WATER RETURN TEMP. (°C) (BLUE BOTTON)	Δ T READING ON TEMP. DIAL	WATER FLOW M³	ENERGY MWh	OIL DAY TANK GUAGE (LITRES)
MAR 1	9.00	-20	62	70	8	23031.8	262.94	145.00
2	9.00	-38	64	58	18	23218.7	264.94	"
3	11.00	-20	58	50	10	23424.7	267.36	"
4	9.00	-19	62	60	2	23771.1	270.76	"
9	8.30	-8	60	62	6	24493.5	276.89	"
10	8.30	-8	70	64	18	24666.9	278.51	"
11	8.45	-12	64	62	10	24848.0	280.72	"
14	8.30	-22	60	52	8	25397.0	286.57	"
15	8.30	-20	62	52	10	25585.1	288.53	"
16	8.30	-20	60	48	12	25783.0	290.61	"
17	8.30	-16	58	48	10	25955.1	292.57	"
18	8.30	-10	58	48	10	26136.7	294.54	"
23	11.30	-15	60	42	18	27079.4	304.01	"
24	9.00	-15	58	48	10	27258.2	305.98	"
25	10.00	-16	60	50	10	27432.5	307.80	"
28	11.00	-20	58	60	2	27996.3	309.83	"
29	9.00	-21	58	62	8	28167.6	310.67	"
30	9.00	-15	60	60	0	28345.0	311.41	"

TABLE 1.

LAC LA MARTRE HEAT RECOVERY STUDY

DATE	TIME	OUTSIDE AIR TEMP.(°C)	WATER SUPPLY TEMP. (°C) (RED BOTTON)	WATER RETURN TEMP.(°C) (BLUE BOTTON)	Δ T READING ON TEMP. DIAL	WATER FLOW M³	ENERGY MWh	OIL DAY TANK GUAGE (LITRES)
APR 5	10·00	2	68	62	6	29434·7	315·07	145·00
6	10·00	-2	68	60	8	29617·2	316·49	"
7	9·00	-6	56	50	6	29789·3	317·70	"
8	10·00	-10	62	38				
11	9·30	-8	58	50	8	30546·3	323·78	145·00
15	9·00	-8	62	54	8	31266·7	329·07	"
18	9·00	-4	72	64	8	31814·0	333·17	.
20	11·00	-3	72	64	8	32363·7	337·67	"
26	10·50	-8	72	64	10	33249·6	344·59	"
27	11·10	-8	73	65	10	33437·5	346·18	"
28	9·30	-6	72	64	10	33601·6	347·65	"

TABLE 1

LAC LA MARTRE HEAT RECOVERY STUDY

DATE	TIME	OUTSIDE AIR TEMP.(°C)	WATER SUPPLY TEMP. (°C) (RED BOTTON)	WATER RETURN TEMP.(°C) (BLUE BOTTON)	Δ T READING ON TEMP. DIAL	WATER FLOW M³	ENERGY MWh	OIL DAY TANK GUAGE (LITRES)
MAY 2	9.00		58	52	6	34513.5	354.93	145.00
3	9.00		68	64	4	34696.4	356.52	"
4	9.00		66	58	10	34886.7	358.12	"
5	9.00		70	68	4	35054.1	359.60	"
9	9.00	-1	56	50	6	35574.0	363.45	"
10	11.00	-1	64	60	4	35769.9	364.57	"
11	11.00	0	72	72	0	35988.9	364.88	"
12	10.00	2	54	46	8	36096.8	366.08	"
13	9.00	1	56	48	8	36286.2	367.95	"
16	9.00	-4	54	50	4	36818.3	372.97	"
17	9.00	-3	60	50	10	36985.8	374.72	"
18	9.00	-1	66	60	6	37161.1	376.25	"
19	9.00	0	60	54	6	37335.2	377.99	"
20	9.00		66	58	8	37505.2	379.61	"
24	9.00		68	60	8	38205.2	385.82	"
25	9.00		66	56	10	38380.5	387.52	"
26	9.00		64	54	10	38546.1	389.14	"
27	10.30		68	60	8	38727.1	390.95	"
30	9.00		66	60	6	39220.9	395.40	"
31	9.00		68	62	6	39389.3	396.80.	"

TABLE 1.

LAC LA MARTRE HEAT RECOVERY STUDY

DATE	TIME	OUTSIDE AIR TEMP.(°C)	WATER SUPPLY TEMP. (°C) (RED BOTTON)	WATER RETURN TEMP.(°C) (BLUE BOTTON)	ΔT READING ON TEMP. DIAL	WATER FLOW M³	ENERGY MWh	OIL DAY TANK GUAGE (LITRES)
JUNE 1	9.00	4	64	56	8	39556.9	398.28	145.00
2	8.30	4	64	54	10	39723.2	399.85	"
3	9.30	6	72	64	8	39903.4	401.42	"
6	9.30	8	68	60	8	40402.9	405.52	"
7	9.15	6	68	62	6	40569.5	407.01	"
8	9.25	5	68	62	6	40749.6	408.50	"
9	8.35	8	72	64	8	40912.8	409.95	"
10	9.20	10	74	64	10	41085.9	411.54	"
13	10.00	14	76	66	10	41589.1	415.25	"
15	9.35	17	74	66	8	41921.7	417.90	"
16	9.35	18	58	52	6	42094.1	419.18	"
19	4.30	14	68	60	8	42643.7	422.61	"
20	10.40	14	62	56	8	42771.9	422.82	"

TABLE 2 - INTERIM PREDICTIONS, FEBRUARY 1983

1983	Predicted Generator Electrical Output KWH	Predicted Generator Heat Output (Recoverable)	Predicted School Heat Requirements KWH	Predicted Degree Days
Jan.	53,325	70,389	60,634	1,360
Feb.	55,000	72,930	51,288	1,200
Mar.	50,500	66,660	44,517	1,050
Apr.	45,500	60,060	29,254	690
May	34,500	45,747	13,567	320
Jun.	30,500	40,443	5,088	120
Jul.	26,000	34,476	2,544	60
Aug.	20,000	26,520	5,045	119
Sep.	45,000	59,670	13,143	310
Oct.	51,000	67,626	27,558	650
Nov.	53,000	70,278	41,549	980
Dec.	55,500	73,593	54,946	1,296

TABLE 3 - INTERIM HEAT RECOVERY FINANCIAL EVALUATION, FEBRUARY 1983

Present value of capital investment: $185,000
Total Fuel Saving: : $ 45,314 litres per year.

Payment Number	Total Fuel Saving (PV)	Principal Outstanding(PV)
1	$ 30,224	$154,776 -
2	$ 59,015	$125,985 -
3	$ 86,666	$ 98,334 -
4	$113,343	$ 71,657 -
5	$139,121	$ 45,879 -
6	$164,823	$ 20,177 -
7	$189,895	$ 4,895
8	$213,888	$ 28,888

Discount Rate: 10%

The break-even occurs in the seventh year.

There is an additional cost, for the heat recovery system, of the electricity for the recirculation pump. This amounts to $2,079 per year.

Due to the present situation, when the discount rate and inflation rate are so unstable, the above table can only be an approximation.

TABLE 4 - FINAL DATA, AUGUST 1983

1983	Generator Electrical Output KWH	Generator Heat Output (Recoverable)	School Heat Requirements KWH	Degree Days
Jan.	53,325	70,389	60,634	1,370
Feb.	51,200	67,584	54,960	1,247
Mar.	30,875	40,755	50,090	1,053
Apr.	39,375	51,975	38,820	693
May	36,450	48,114	44,810	315
Jun.	34,500	45,540	34,780	156
Jul.	28,400	37,488	13,377	60
Aug.	30,200	39,864	26,531	119
Sep.	36,100	47,350	32,870	310
Oct.	36,932	48,750	36,410	650
Nov.	40,237	53,113	46,620	980
Dec.	45,265	59,750	57,120	1,296

TABLE 5 - HEAT RECOVERY FINANCIAL EVALUATION, AUGUST 1983

LAC LAMARTRE SCHOOL RECOVERY OPTION - EX + JW

NCPC/GNWT EQUIVALENT FUEL COST SHARING RATIO % 100 : 0.0
PRESENT VALUE - CAPITAL INVESTMENT = $ 249000.00

FINANCIAL EVALUATION

PAYMENT NO.		TOTAL FUEL SAVING PV		PRINCIPAL OUTSTANDING PV
1	$	26488.56	$	222511.44-
2	$	53220.13	$	195779.87-
3	$	80196.94	$	168803.06-
4	$	107421.25	$	141578.75-
5	$	134895.33	$	114104.67-
6	$	162621.46	$	86378.54-
7	$	190601.95	$	58398.05-
8	$	218839.15	$	30160.85-
9	$	247335.41	$	1664.59-
10	$	276093.10	$	27093.10
11	$	305114.62	$	56114.62
12	$	334402.39	$	85402.39
13	$	363958.86	$	114958.86
14	$	393786.49	$	144786.49
15	$	423887.77	$	174887.77
16	$	454265.21	$	205265.21
17	$	484921.33	$	235921.33
18	$	515858.71	$	266858.71
19	$	547079.92	$	298079.92
20	$	578587.56	$	329587.56

TOTAL FUEL SAVING = 49780. LITRES PER YEAR
DISCOUNT RATE - 9 %; FUEL INFLATION RATE - 10 %

BREAK - EVEN AT YEAR 9

RETROFIT OPTIONS FOR PRIVATE DWELLINGS

BY
JAMES OLNEY, JR.*
RICHARD D. SEIFERT**

* Energy Specialist and Residential Builder, Rainbow Ventures, Residential Building.
**Assistant Professor, Cooperative Extension Service and Institute of Water Resources, University of Alaska, Fairbanks, Alaska

ABSTRACT

Some very interesting and exciting things are happening in the field of home insulation and commercial retrofits. New materials for energy conservation have brought about more affordable options, but at the same time, the characteristics of some of these materials require careful attention to details when installing them as retrofits. In addition, the state of Alaska has had an ongoing energy audit program coupled to a retrofit energy conservation loan program ($5,000 limit) which has provided an incentive to insulation retrofits in Alaskan residential construction.

This review of retrofit options will first address what is perhaps the most pressing question of energy efficient retrofits: What happens to moisture transport and vapor pressures in the wall when insulation is added? To answer this, the temperature gradients and allowable relative humidities (to limit moisture condensation) are presented in tabular form. These tables are prescriptive tools and can be used to show where moisture problems will occur if water vapor gets to different sections of the wall due to vapor barrier holes or failures.

In addition, a review of several ongoing retrofit projects will be presented photographically. The construction techniques used in each case will be described and their pros and cons discussed. Many retrofits involve the addition of foil-faced, urethane foam insulation on the exterior of a structure, often with the attachment of aluminum siding as the exterior sheathing. Recommended installation methods for this retrofit will be described. Each project will utilize some products and techniques which differ from the others. This provides a means of comparing different materials as well as their properties.

Presentations will include:

--Basement insulation: outside vs. inside.

--Roof insulation: hot and cold roofs.
truss lift and avoidance.
insulation types.
attic scuttle openings.
ventilation.

--Vapor barriers: retrofit of a vapor barrier.
vapor barrier paints.
polyethylene.
avoiding perforations.

--Wall retrofit: foil-faced, urethane foams.
extruded polystyrene.
interior retrofits.
recommended wall features and designs.

1. INTRODUCTION

The older buildings of Alaska, especially those more than ten years old, often have poor insulation and inadequate protection from vapor and moisture problems. Although newer structures are generally better constructed, some building techniques still do not adequately protect the insulation from moisture. The materials available today make it possible to construct better homes and buildings with economical operating costs, while employing our best strategies for making the buildings work well. Some of the biggest challenges we face, however, relate to retrofit of older buildings with insulation and vapor barriers. The various new insulating materials, and vapor barrier placement and installation techniques make retrofit of these items a job not to be taken lightly. Some insulations are aluminum foil faced, and have vapor barrier characteristics. Vapor barrier paints are available, but we really don't know how well they work in subarctic climates where vapor pressure differentials are very high between the inside and outside of the building. Other materials may have unforeseen characteristics which ultimately lead to problems. One need only recall the recent nationwide fury over the use of urea-formaldehyde foam as a retrofit insulation. This foam, when it cures, releases formaldehyde vapor, which causes unhealthy conditions in the residence. When used as a retrofit, this insulation was often installed without a vapor barrier, and consequently, much of the formaldehyde released during curing entered the living area of the homes. Ultimately this problem resulted in nationwide condemnation of the use of urea-formaldehyde as an insulating material, and suits were filed in its defense as well by homeowners. The lesson is ominously clear: Great care and careful attention to details and material characteristics are in order when considering a residential retrofit of thermal insulation.

This paper will provide a review of some of the physical considerations of retrofit, such as moisture transport and vapor sealing. It is important to raise questions about the in situ performance of insulating materials and vapor barriers so that these can be evaluated and tested through further research, if needed. Some hypothetical retrofit schemes will be discussed in order to describe the physical "pros and cons" of the options.

Finally, a review of several retrofit projects from the Fairbanks, Alaska area will be included. Fairbanks, with an approximately 14,500 °F-day (8,000 °C-day) heating index, and a design temperature of -47°F (97.50 percentile) provides a natural laboratory. It also has a housing stock with a wide range of ages. Energy costs are high in Fairbanks, with fuel oil (number 1) averaging $1.149, and electricity costs averaging 11¢ for 500 kwh/month.[1] An additional incentive to retrofit older houses is also bringing increasing attention to retrofits. The state of Alaska has a continuing energy audit program coupled to a retrofit energy conservation loan program ($5,000 limit). This program loans money at an interest rate of 5% for energy conserving improvements which are recommended in the audit program, and which have a ten year or less payback period.

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[1] The Fairbanks electricity prices are weighed by the number of customers at both local electric utilities.

2. VAPOR TRANSPORT--HOW DOES IT OCCUR?

Generally, the moisture level (relative humidity) in a building is related to the interior temperature, vapor tightness of the vapor barrier, and the ambient outdoor temperature and relative humidity. It is extremely variable, however, and also depends greatly on occupancy levels, and cooking, toilet and laundry uses, which are humidity-generating processes. The relative humidity in the house fluctuates with changes in the occupancy, cooking, and other moisture sources, which changes the vapor pressure in the building. It is the vapor pressure which is the driving force for moving moisture from the inside of the building to the outside. The vapor pressure is a function of both the temperature and the relative humidity. Table 1 gives the vapor pressures for saturated air for temperatures from -65°F to 98°F. Saturated air simply means the air is at 100% relative humidity. Note that as the temperature drops, so does the vapor pressure. For instance, if it is 68°F in a room, and outside the temperature is -35°F, then the pressure difference at saturation is (.6903--.0052) in Hg = .6851 inches of mercury. This means that a very real pressure difference exists between the inside and outside of a structure. This pressure difference serves to force water vapor from the inside (high vapor pressure) to the outside (low vapor pressure). This is further complicated by the process of condensation. As the moisture moves toward the outside of the wall, it cools and then condenses. When condensation occurs, the water produced will wet the insulation in the wall and lower its insulating value. Ultimately, the water may even freeze. As long as this temperature and pressure difference persists, the moisture will condense and the amount of water and/or ice in the wall will increase. If it reaches the level where it is 20% by weight of the wood framing in the wall, mildew, dryrot and other fungi may begin to destroy the studs and framing. All these problems are prevented if a tightly sealed vapor barrier is placed on the warm side of the wall. The purpose of the vapor barrier is to insure that most moisture is kept out of the wall where it only does mischief. In the cold arctic and subarctic climates of Alaska and northern Canada, vapor barriers are essential to the satisfactory performance of insulated buildings.

There is some margin as to where the vapor barrier can be placed in the wall. In Canada, recommended placement of the vapor barrier is at a depth of no more than one third the R-value of the wall. This is the "2/3-1/3 rule" commonly quoted in Canada. At least two thirds of the R-value of the insulation is kept on the cold side of the vapor barrier to insure that condensation will not occur at the vapor barrier at even the worst conditions. In subarctic climates, the rule should be "3/4-1/4 or 4/5-1/5 because the extremely low temperatures (-40 to -60°F) sometimes experienced in these climates increases the chance for condensation at the point in the wall where the vapor barrier is located.

3. AN EXAMPLE OF A WALL RETROFIT

This points up one of the important factors to consider when retrofitting with an insulating material that is also a vapor barrier. Table 2 is a listing of some important information concerning what generally happens in a retrofitted wall, especially if the retrofit is a vapor barrier material. Table 2 shows the temperatures and allowable relative humidities at the inside surfaces of the different parts of the

TABLE 1

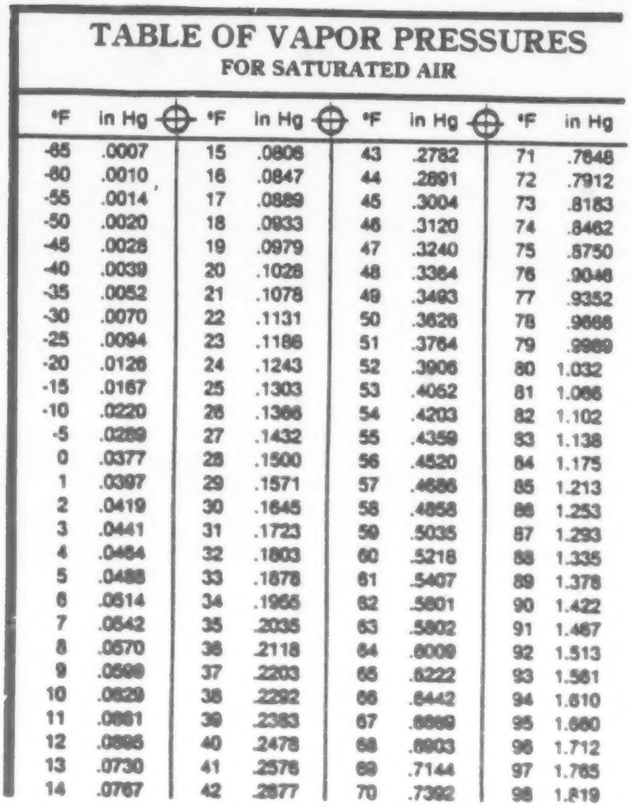


TABLE OF VAPOR PRESSURES

FOR SATURATED AIR

°F	in Hg	°F	in Hg	°F	in Hg	°F	in Hg
-65	.0007	15	.0806	43	.2782	71	.7648
-60	.0010	16	.0847	44	.2891	72	.7912
-55	.0014	17	.0889	45	.3004	73	.8183
-50	.0020	18	.0933	46	.3120	74	.8462
-45	.0028	19	.0979	47	.3240	75	.8750
-40	.0039	20	.1028	48	.3364	76	.9046
-35	.0052	21	.1078	49	.3493	77	.9352
-30	.0070	22	.1131	50	.3626	78	.9666
-25	.0094	23	.1186	51	.3764	79	.9989
-20	.0126	24	.1243	52	.3906	80	1.032
-15	.0167	25	.1303	53	.4052	81	1.066
-10	.0220	26	.1366	54	.4203	82	1.102
-5	.0289	27	.1432	55	.4359	83	1.138
0	.0377	28	.1500	56	.4520	84	1.175
1	.0397	29	.1571	57	.4686	85	1.213
2	.0419	30	.1645	58	.4858	86	1.253
3	.0441	31	.1723	59	.5035	87	1.293
4	.0464	32	.1803	60	.5218	88	1.335
5	.0488	33	.1878	61	.5407	89	1.378
6	.0514	34	.1955	62	.5601	90	1.422
7	.0542	35	.2035	63	.5802	91	1.467
8	.0570	36	.2118	64	.6009	92	1.513
9	.0599	37	.2203	65	.6222	93	1.561
10	.0629	38	.2292	66	.6442	94	1.610
11	.0661	39	.2383	67	.6669	95	1.660
12	.0695	40	.2478	68	.6903	96	1.712
13	.0730	41	.2576	69	.7144	97	1.765
14	.0767	42	.2677	70	.7392	98	1.819

TABLE 2

TEMPERATURE GRADIENTS (DEGF) AND ALLOWABLE RELATIVE HUMIDITIES (PCT):
SECTION--WALL, 2X6, 6 FIBERGLASS & 2 RIGID FOAM

```
R-VALUES      DESCRIPTION
                            (DEGF)  -60.0   -50.0  -40.0  -30.0  -20.0  -10.0   0.     10.0   20.0   30.0
  0.17    EXTERIOR FILM 15 MPH
                            (DEGF)  -59.4   -49.4  -39.5  -29.5  -19.6   -9.6   0.3    10.3   20.2   30.2
  0.01    METAL SIDING
                            (DEGF)  -59.3   -49.4  -39.5  -29.5  -19.6   -9.6   0.3    10.3   20.2   30.2
  1.56    POLYSTYRENE BEAD 5/8
                            (DEGF)  -53.7   -44.2  -34.7  -25.2  -15.7   -6.2   3.3    12.8   22.3   31.8
  0.      VAPOR SEAL POTENTIAL
                             (PCT)    0.3     0.5    0.9    1.5    2.6    4.4   7.2    11.7   18.6   28.9
 11.00    POLYSTURENE FOAM 2
                            (DEGF)  -13.9    -7.9   -1.3    5.0   11.3   17.6  24.0    30.3   36.6   42.9
  0.      VAPOR SEAL POTENTIAL
                             (PCT)    2.9     4.1    5.7    7.9   10.9   14.9  20.1    27.0   36.0   47.6
  0.91    AIR SPACE
                            (DEGF)  -10.6    -4.6    1.5    7.5   13.6   19.6  25.7    31.7   37.8   43.8
  0.      VAPOR SEAL POLYETHYLENE
                             (PCT)    3.4     4.8    6.6    9.0   12.2   16.3  21.8    28.9   37.9   49.6
  0.78    PLYWOOD 5/8 1-11
                            (DEGF)   -7.6    -2.0    3.8    9.7   15.5   21.3  27.1    33.0   38.8   44.6
  0.      VAPOR SEAL POTENTIAL
                             (PCT)    4.0     5.5    7.4   10.0   13.4   17.7  23.3    30.5   39.7   51.3
 19.00    FIBERGLASS 6
                            (DEGF)   60.9    61.2   61.6   61.9   62.2   62.5  62.9    63.2   63.5   63.9
  0.      VAPOR BARRIER
                             (PCT)   99.9    99.9   99.9   99.9   99.9   99.9  99.9    99.9   99.9   99.9
  0.45    SHEET ROCK 1/2
                            (DEGF)   62.5    62.7   62.9   63.1   63.3   63.5  63.7    63.9   64.1   64.3
  0.68    INTERIOR FILM
                            (DEGF)   65.0    65.0   65.0   65.0   65.0   65.0  65.0    65.0   65.0   65.0
 34.56    Total insulation R-value

Total heat conductance, U=1/R
 0.0289 BTU/HR/SF/DEGF
```

Table courtesy of Axel R. Carlson

wall. The term allowable relative humidity refers to the relative humidity in the building. The allowable relative humidity is that humidity level above which condensation of the inside room air would occur if allowed to get to that particular point in the wall. Let's consider an example from Table 2 to clarify the terms.

The columns in Table 2 are headed by outdoor air temperatures from -60° to +30°F. The wall described in the table is a 2"x6" standard frame wall with six inches of fiberglass insulation retrofitted with two inches of extreded polystyrene foam, such as DOW blue styrofoam, and then finished on the exterior with styrofoam-filled aluminum siding. Let's look at what the predicted temperatures and allowable relative humidities are in the wall at the point of the original exterior plywood and the surface of the retrofitted insulation. Notice that an air space is also included between the plywood and the retrofit insulation, as required by the National building code of Canada, and recommended by the manufacturers of vapor resistant insulations. The plywood itself is a rather good vapor barrier, with a perm rating of 0.7 (ASHRAE, 1981), and often it is removed in an insulation retrofit. In this example, however, at -60°F outside temperature (first column, Table 2) the allowable relative humidity at the inside surface of the plywood is 4.0%. Clearly, if any moist air from the inside of the building leaks to this point in the wall, condensation will occur, and ice will build up. The same holds true for the surface of the retrofitted insulation, where the allowable relative humidity is even lower, 2.9%. This example serves to clearly show the potential for moisture accumulation at the surface of a vapor barrier insulating material. This factor has long been recognized as a potential problem with plastic foam insulations (styrene and foil-faced polyurethane foams).

To combat moisture buildup on the warm side of the retrofit vapor barrier insulations, manufacturers recommend installation of a vent strip to allow air to pass along the warm (inner) side of the insulation. This is intended to vent any moisture out of the space to keep it from accumulating. However, it will also increase the heat loss from the wall and diminish the effectiveness of the new insulation. To counteract this we recommend placement of batt of sill sealer-type fiberglass insulation at the top and bottom of the wall vent strip. Covering the entry and exits to the vented area with a spun-olefin, vapor-porous, paper (i.e. Dupont TYVEK^{R}) would also cut air flow but still allow moisture to escape from the vent space.

Here are some options when considering an exterior retrofit of vapor barrier insulation:

A. If the wall cavity is vented, then the vent strip requirement could be waived.
   1. The Saskatchewan Research Council suggests using 2" x 4" top plates with 2" x 6" studs which allows the wall to breath into the attic.
   2. The top plates could have holes drilled between stud spaces.
   3. Install two button vents in each stud cavity at the top and bottom of the wall.
      Items 1 and 2 do not conform to the present fire code which requires continuous fine blocking at the top of the wall.
      As a note, many double wall designs do have open top plates.

B. Avoid the venting problem entirely!
When extensive renovations are to be performed, the inside walls can be effectively covered with rigid foam. We highly recommend the Scandinavian cross-hatch system. The foam is placed on the wall, then a 6 mil vapor barrier. Then, fur out with horizontal 2" x 2" furring strips and run new wiring in the 2" x space before adding an inch of fiberglass and then install the sheetrock. This system makes an excellent vapor barrier possible in addition to an easy rewiring job that many older homes can use. See figure 1 for an example of this type of wall system.

C. Put the vapor barrier on the outside wall!
The amount of exterior insulation required to make this system work depends upon your outside design temperatures and inside relative humidity. Author Ed McGrath (1981) describes the rule: "If there are, on the cold side of the vapor barrier, four times as many R's as on the warm side, you're safe. For safety at -60°F, a ratio of 5:1 is advantageous, and a very high humidity house should have an even higher ratio. And conversely, if it never gets colder than 0°F where you live a ratio of 2:1 or 3:1 is adequate."

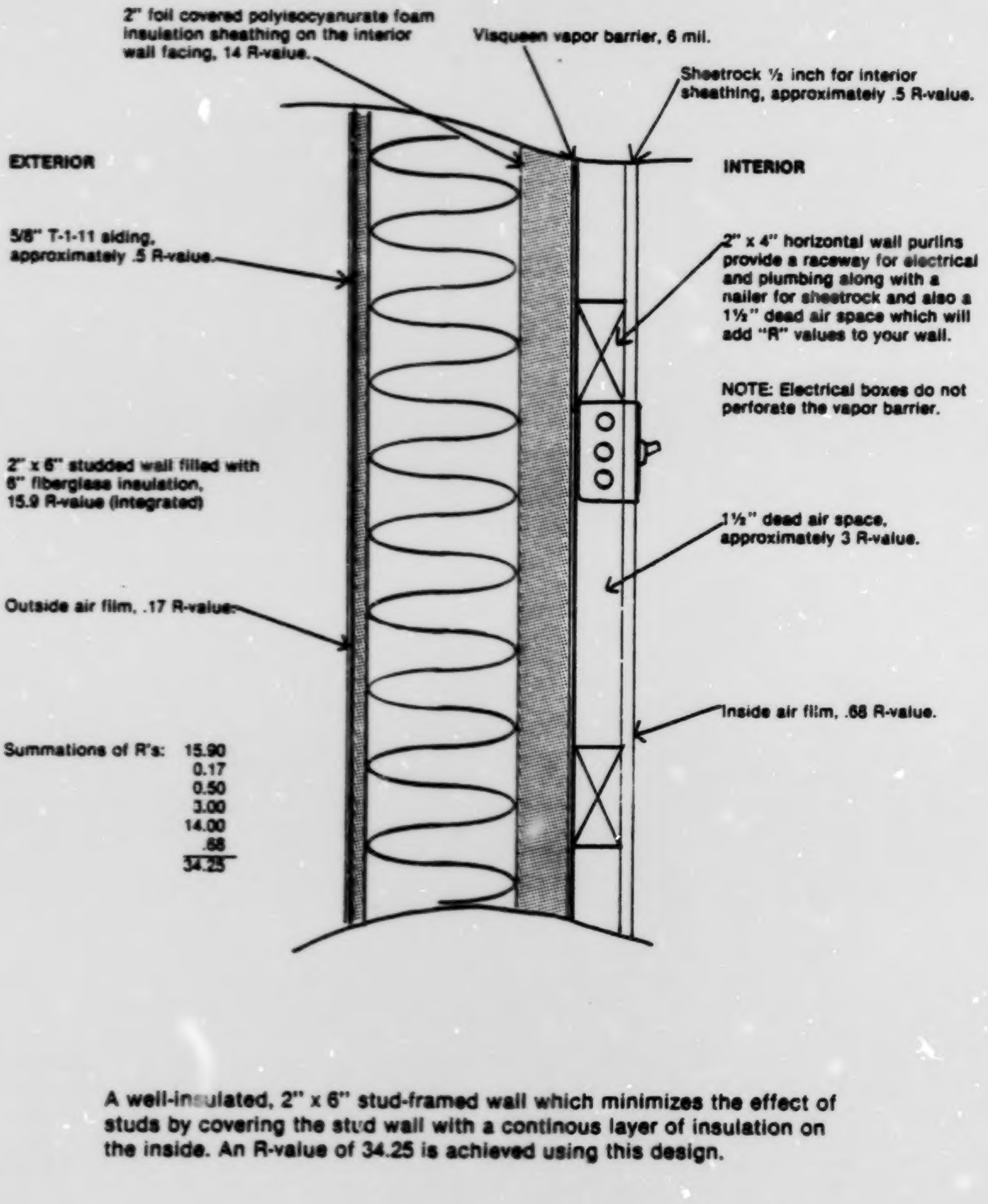
4. SOME EXAMPLES OF RETROFIT TECHNIQUES:

4.1 Basements

Are a unique situation for insulation retrofits because they are below grade, and soil contact and moisture limits the options for external insulation. To work well, an exterior basement insulation should be durable, not biologically degradable, water resistant, and a water vapor barrier. Only a few available products can meet this regorous set of demands, and extruded polystyrene foam does it best. Fiberglass Canada has recently marketed a product called Baseclad EBWI, a semi-rigid fiberglass insulation specially designed for exterior basement insulation. Unfortunately, it is unavailable in the U.S., to the authors' knowledge.

Retrofitting a basement on the exterior avoids all the miseries of interior additions, such as moving electrical outlets, plumbing, lights, and decreasing the living area in the residence. If insulation is added to the interior as a retrofit, virtually everything on the old walls must be moved, changed or discarded, and an entirely new finished surface must be added. An exterior retrofit can avoid most of this problem. However, is it less expensive to excavate and add insulation to the outside of a basement? From our Fairbanks experience, the answer appears to be a definite yes. Just such a basement retrofit was done in Fairbanks using blue Dow styrofoam. The excavation was done for $250 U.S.(1983), with only slight damage to a water line. The resulting excavation allowed for ease of installation, and backfilling was a simple matter. It is also an excellent opportunity to reseal a basement before the insulation is installed, should that be necessary. Backfilling cost an additional $200. The entire retrofit cost about $2,000 U.S., and is estimated by the homeowner (and confirmed by a state energy audit) to have about a 5-6 year payback. This is a positive example of the economic worth of a retrofit, and it also will save twenty to thirty percent of the heat loss from the entire house.

FIGURE 1. Cross-section of a well-insulated, 2" x 6" stud-framed wall.


2" foil covered polyisocyanurate foam insulation sheathing on the interior wall facing, 14 R-value.
Visqueen vapor barrier, 6 mil.
Sheetrock ½ inch for interior sheathing, approximately .5 R-value.
EXTERIOR
INTERIOR
5/8" T-1-11 siding, approximately .5 R-value.
2" x 4" horizontal wall purlins provide a raceway for electrical and plumbing along with a nailer for sheetrock and also a 1½" dead air space which will add "R" values to your wall.
NOTE: Electrical boxes do not perforate the vapor barrier.
2" x 6" studded wall filled with 6" fiberglass insulation, 15.9 R-value (integrated)
1½" dead air space, approximately 3 R-value.
Outside air film, .17 R-value.
Inside air film, .68 R-value.
Summations of R's: 15.90
0.17
0.50
3.00
14.00
.68
34.25

A well-insulated, 2" x 6" stud-framed wall which minimizes the effect of studs by covering the stud wall with a continous layer of insulation on the inside. An R-value of 34.25 is achieved using this design.

4.2 Roof Insulation Considerations:

People will generally put up with a great deal of aggravation from a roof before they make things right, whether it is a leaky roof, condensation problems (sometimes thought to be a leaky roof), or inadequate insulation. Roofs also must have holes cut in them for plumbing vents, chimneys, and ventilation outlets. Also, the ultimate destination for water vapor which leaks out through the vapor barrier in the floor, walls, and ceiling is often the roof cavity. So, the roof is a focal area for every conservation, vapor protection, and ventilation.

Ventilation is related to the concept of "hot" and "cold" roofs. A hot roof is closed and unvented (either intentionally or otherwise), and gets its name from the fact that the roof surface will warm up as the snow depth on it increases. This may, and usually does, result in some melt of the snow at the roof surface. This water then travels down the slope of the roof to the eave where the roof is no longer "hot" because it is now over the unheated eave. The resulting freezing water creates an ice dam at the eave and icicles which hang down from the eaves, usually building in size over the winter. Although icicles are a quaint, often associated feature of the north, for a properly designed roof, they should not be present. The proper design is a "cold" roof. In this design the roof is kept cold by ventilating it: allowing for passage of air in a continuous flow from the eaves, into a space under the roof surface but above the insulation. This maintains the surface of the roof near the temperature of the outdoor air, and vents any moisture that reaches the insulated roof area, keeping it from accumulating there (see Figure 2). It is this design which is most desirable and effective for roofs in subarctic climates.

In Fairbanks there is an entire community of duplexes which were built in the late 60's, all with flat, unvented roof designs. Most of the duplexes are still occupied, but nearly all experienced roof failures: either moisture damage occurred, or physical failures resulted from deterioration of the roof. Orginally, the roofs were framed with rafters, approximately two-inches of fiberglass insulation, and no vapor barrier. The surface was finished with felt, and then hot mopped with roofing tar over a roofing membrane. An owner of one building who had just examined his roof in June, 1983, related in a recent discussion that he found the insulation saturated, and moisture damage, mostly mildew, on the rafters. The owner requested advice as to whether or not to remove the wet insulation before proceeding to build another roof system over the top of the old one. It was suggested that the wet insulation should indeed be removed, as mildew might continue for some time before the remaining moisture was evaporated. The owner complained of huge heating bills. It is clear why. The effective insulating value of the roof in winter was probably R4 or less. The owner intends to retrofit an entirely new 4 in 12 pitch, vented roof over the building, install a vapor barrier directly over the old roof, then place [illegible] inches of fiberglass in the roof.

An important detail in retrofitting insulation into roof spaces is to not block the vent space over the wall plates. This is especially a problem if insulation is blown into the attic. The blown-in insulation can easily fill the vented space and cause "hot roof" conditions. Figure 3 shows the best way to avoid this. A plywood baffle or manufactured plastic baffles can be placed above the wall top plates against the roof to insure

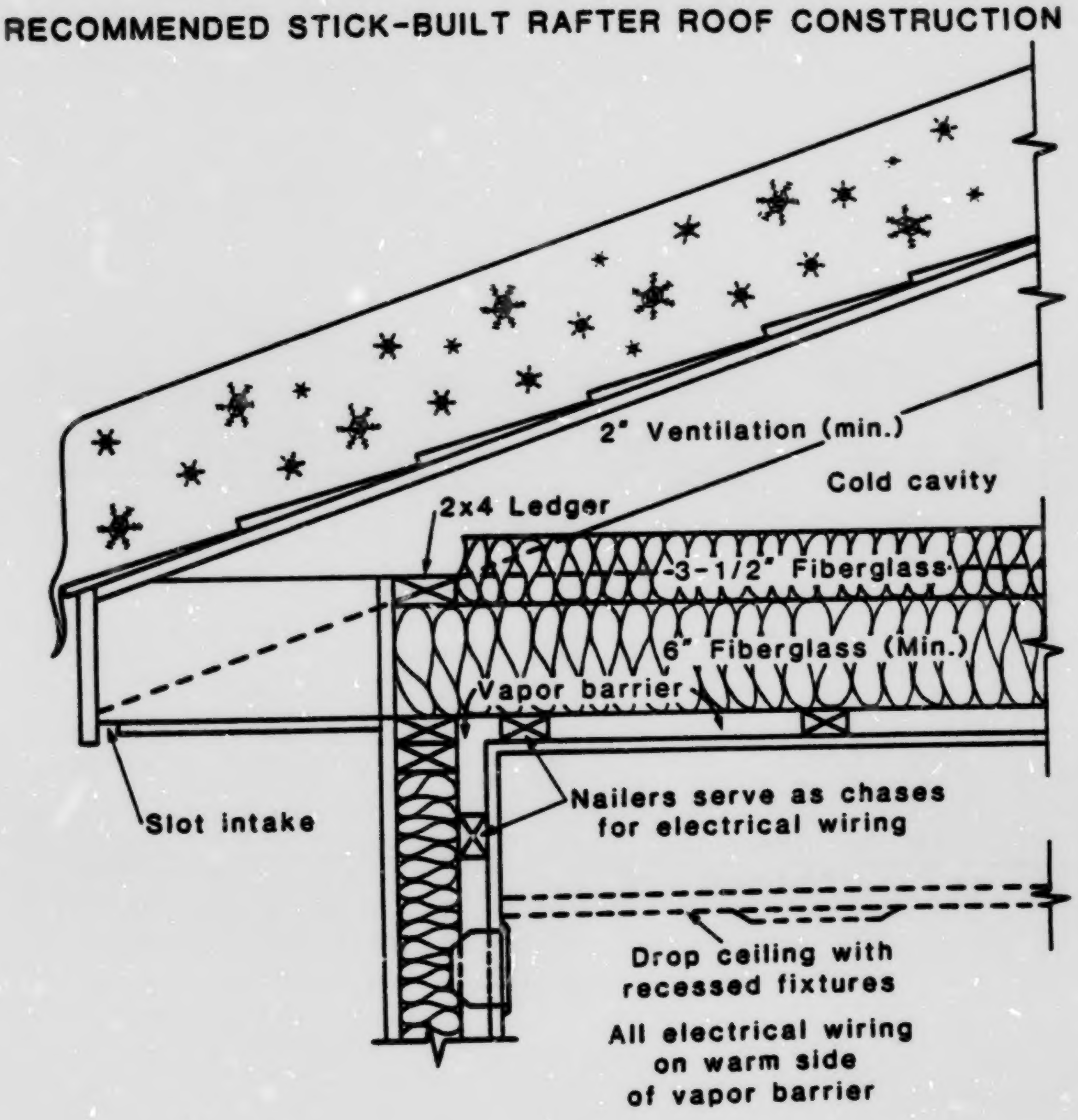

RECOMMENDED STICK-BUILT RAFTER ROOF CONSTRUCTION
2" Ventilation (min.)
Cold cavity
2x4 Ledger
3-1/2" Fiberglass
6" Fiberglass (Min.)
Vapor barrier
Slot intake
Nailers serve as chases for electrical wiring
Drop ceiling with recessed fixtures
All electrical wiring on warm side of vapor barrier

FIGURE 2: A classic "cold roof" design for rafter construction. The same design can be applied to truss roofs.

RECOMMENDED CANTILEVER ROOF CONSTRUCTION

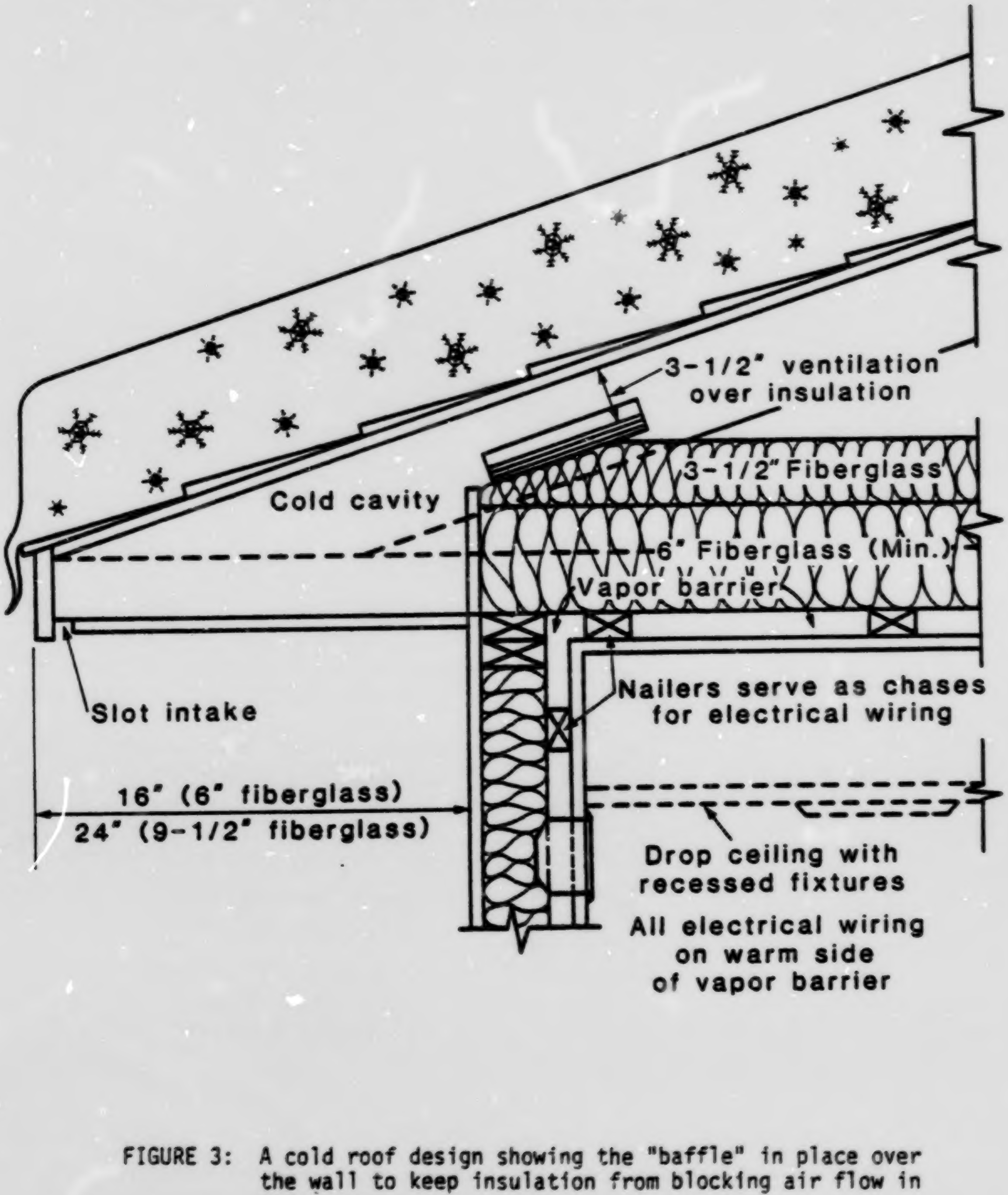

3-1/2" ventilation
over insulation
3-1/2" Fiberglass
Cold cavity
6" Fiberglass (Min.)
Vapor barrier
Slot intake
Nailers serve as chases
for electrical wiring
16" (6" fiberglass)
24" (9-1/2" fiberglass)
Drop ceiling with
recessed fixtures
All electrical wiring
on warm side
of vapor barrier

FIGURE 3: A cold roof design showing the "baffle" in place over the wall to keep insulation from blocking air flow in this area.

that free flow of ventilation air is maintained in spite of the extra insulation. Further details on roof design, ventilation and moisture control can be found in Wolfert and Hinrichs (1974), and Carlson (1973).

One special situation about ventilation of the roof space needs addressing. Recommendations from Wolfert and Hinrichs (1974) for fixed louver attic ventilation call for a "balanced ridge and soffit vent system . . . Half of the total net free ventilating area should be at the ridge, the other half at the soffits." For subarctic climates, a gable end vent should be used, or a cupola vent, as opposed to a ridge vent. The problem of a ridge vent is that snow cover will normally block it for a substantial portion of the year, causing hot roof conditions to occur. Ridge vents are not recommended for arctic or subarctic climates. Roof louvres are not recommended for the same reason.

Lastly, scuttle openings inside a dwelling are commonly included to provide access to the attic space. These are vapor leaks of great magnitude if they are not vapor proofed. Our recommendation is that they be left out of the plan. Access to the attic space of a cold roof can be provided from the gable ends preferably through a small door.

4.3 Insulation Types:

Economics, fire safety, and in situ, delivered performance are the critical factors for insulation evaluations.

For exterior basement retrofits, there are few choices, since the earth contact requires a waterproof and non-degradable insulation. Extruded polystyrene appears to be the top contender. Urethane foams are utilized as is the new deuse-fiberglass EBWI insulation. Fire safety is not a critical feature if the basement retrofit is on the exterior.

For walls the conditions become more complex. The option of exterior retrofit has been previously discussed. Vapor control in the wall should be managed with a 6-mil polyethylene sheet placed as close to the warm surface of the wall as possible. Vapor barrier paints can be used if the existing vapor barrier is of questionable quality.

Wall insulation must be somewhat incompactible, at least under its own weight. This makes sprayed in place perlite, cellulose, or fiberglass insulation unsuitable for walls. Batt fiberglass, batt mineral wool, and plastic foams of most types, are all viable options for wall insulation, if appropriate vapor protection is provided. Some of the plastic foams are undesirable, especially on the inside of a wall cavity, because of fire code restrictions. Normal fire protection is provided by 1/2" or 5/8" sheetrock on the inside surface of the walls. However, because of possible melting and "flashover" fires which can result from plastic insulations, (i.e., polystyrene, polyurethane, poly-isocyanurate) they are less desirable. Most of the plastics also have the disadvantage of being difficult to vent, which is a result of their structure. If they get wet, they are difficult to dry out. Plastic foams also are presently about twice as expensive per unit R-value as is fiberglass.

Roof insulation can be sprayed in place, because it is usually less than two-feet in depth, and self-compaction will be minimal. Vapor protection with a 6 mil vapor barrier is essential for all blown-in insulations. Batt insulations are also satisfactory. Some fire hazards have occurred from insulating heavily above ceiling lighting fixtures.

Since most sprayed insulations are non-combustible, this is usually not a problem. Cellulose is an exception, however, and it is always advisable to try to test burn the cellulose that will be sprayed into your attic. If properly treated with fire retardant chemicals, it should smoulder slowly and then go out. If not, it is inadequately treated and should not be used. Batt fiberglass or mineral wool have a saving grace which is lacking in the sprayed insulations. Most sprayed and batt insulations will undergo considerable compaction if wetted. The batts can usually be fluffed to a density close to the original recommendation after drying them out, but the sprayed insulations will compact and are very difficult to recover. Removal and replacement is usually required. This again reinforces the importance of adequate vapor protection. All the insulations mentioned for roof applications will perform well if kept dry and at the recommended density.

5. CLOSING COMMENTS:

The history of energy conserving insulation retrofits is just beginning. With each passing season and each new product, we learn more about how insulation works, how vapor moves, and how houses work.

We have tried to present a sampler of experience and advice, and would appreciate further examples of both from the interested reader. There are materials, products, and building techniques available today to match the requirements of our homes and buildings. The more we learn from our mutual experiences through sharing information, the better our homes and lives will be.

6. ACKNOWLEDGEMENT:

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ENERGY CONSERVATION OPTIONS
FOR
ALASKAN MOBILE HOMES

BY

JOHN MUNSON

DEPARTMENT OF COMMERCE & ECONOMIC DEVELOPMENT

DIVISION OF ENERGY AND POWER DEVELOPMENT

ANCHORAGE, ALASKA

ENERGY CONSERVATION OPTIONS FOR ALASKAN MOBILE HOME OWNERS

Introduction

Factory built, mobile homes represent a significant part of the housing stock in Alaska. In some communities over 50% of dwelling units (including apartments) are mobile homes. Because of the type of construction used, mobile homes may well offer the most potential for energy saving retrofit measures. Contrary to what appears to be popular belief, mobile homes can be retrofitted much in the same manner as stick built houses. This paper will discuss the problems and options available to the mobile home owner for reducing energy usage.

The Mobile Home In Perspective

Increasing cost of land and of construction -- coupled with rising interest rates that make mortgage payments prohibitively high -- have combined to make mobile homes an attractive solution for those who want to own their own homes. In recent years the cost of a site built house in Alaska has virtually doubled with mortgage payments in excess of $1,000 per month common. At the same time, Alaska state programs now allow 95% financing of mobile homes with 20 year mortgages. In the past, normally only 75% financing and 10 year mortgages were available. The effects of these factors are, perhaps, demonstrated by the fact that 276 mobile homes were bought in Anchorage during the first eleven months of 1981 as compared to only 181 during the same time frame of 1980.

While the vast majority of the mobile homes are still located within mobile home parks, the practice of locating them on privately owned lots and acreages is becoming increasingly popular. With only a few rare exceptions, almost all the mobile homes in Alaska are found along either the road system or the marine highway. Table 1 shows the location and the numbers of mobile homes in use as of October 1981 within Alaska.

206

STATE OF ALASKA

Division of Motor Vehicles
Mobile Home Listing

Anchorage	5,503
Juneau	826
Sitka	379
Haines	11
Talkeetna	48
Tok	16
Delta Junction	134
Cordova	137
Barrow	2
Kodiak	322
Naknek	2
Glennallen	127
Petersburg	152
Dillingham	14
Seward	63
Soldotna	349
Galena	3
Fairbanks	1,649
Ketchikan	427
Nome	379
Bethel	62
Skagway	16
Valdez	360
Homer	224
Eagle River	391
Palmer	458
Kenai	504
Nenana	35
Kotzebue	14
Wrangell	106
Yakutat	6
Total Mobile Homes:	12,422

TABLE 1

The light weight construction required to make homes mobile has resulted in the mobile home unit having a relatively short life as compared to site built housing. The average expected life of the mobile home is estimated to be between 16-18 years. This figure is improving, however, as the emphasis is shifting away from mobility. A number of mobile home manufacturers now offer 2 x 6 construction with sheetrock or sheetrock-like material for wall covering. Insulation levels of R-19 walls, R-22 floors, and R-38 ceilings are being offered. Table 2 shows the age of the mobile homes in use within Alaska as of October 1981.

STATE OF ALASKA
Division of Motor Vehicles
Mobile Home Report
(count/year)

MODEL YEAR	COUNT
46	2
47	3
48	5
49	8
50	32
51	41
52	48
53	52
54	35
55	66
56	116
57	165
58	130
59	233
60	232
61	304
62	310
63	312
64	379
65	458
66	306
67	360
68	534
69	791
70	1,007
71	883
72	544
73	507
74	792
75	1,255
76	764
77	596
78	737
79	155
80	134
81	122
82	4
TOTAL	12,422

TABLE 2.

The very qualities that account for the popularity of mobile homes -- low cost, mass production, lightweight construction, and transportability -- make them energy wasters. Figure 1 shows a comparison of the amount of energy consumed by various types of dwellings.

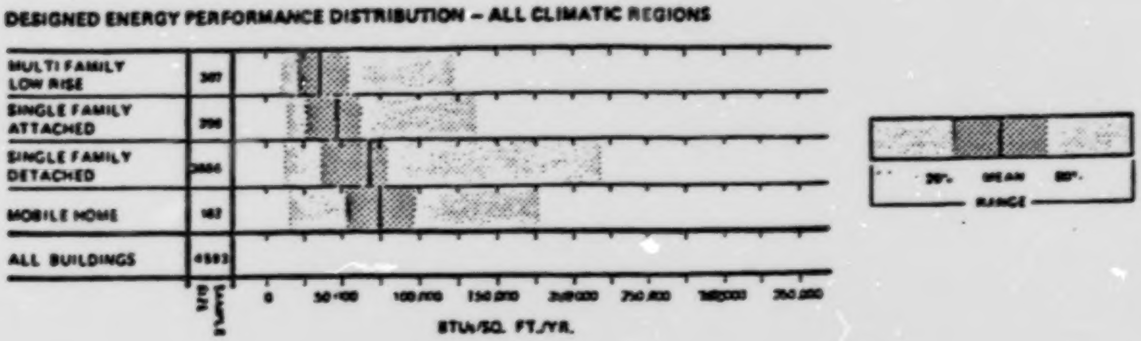


Figure 1.

As stated earlier, mobility is becoming less of a factor in mobile home construction as more people use them as permanently sited homes. This allows manufacturers to build better homes. Unfortunately not many of these adequately insulated units exist in Alaska. Prior to 1972 typical construction of a unit, even for Alaska, involved 2 x 2 or 2 x 3 walls with little or no insulation in the walls or ceiling (and) with single-paned, jalousie windows. From 1972 to 1975, the State of Alaska enforced minimum standards for mobile homes sold in the State. During this time frame, the minimum total resistance values (R-values) of the walls (less windows and doors), ceiling and floor were required to be:

Wall:	R-10
Ceiling:	R-16
Floor:	R-12

The homes had to be designed to withstand the winter design temperature for the area of the State that they were to be sold in. Storm windows were required.

In 1976 the Department of Housing and Urban Development enacted standards for mobile home construction and safety standards pursuant to the requirements of the National Mobile Home Construction and Safety Standards Act of 1974. These standards superseded the State regulations which were then rescinded. The new HUD standards established an overall heat loss coefficient (U-value) of 0.104 BTU/Hr/SqFt/F° (R-9.6) for units to be sold in Alaska. The standards require at least some insulation be provided to all cavities of the ceiling, wall and floor but falls short of setting specific requirements for each component. Each mobile home is required to have a certificate affixed to an interior surface that states either the overall thermal coefficient or the "U" value for each component of the structure. Vapor barriers and storm windows are required for a unit sold in Alaska.

Unfortunately there is little or no interest in the enforcement of these standards. No office could be found within the State of Alaska with that responsibility. The HUD regulations do, however, establish procedures for individual owners to file complaints and provide for penalties if the manufacturer does not correct identified problems. HUD standards for mobile homes can be found in Federal Register, Vol. 40, No. 244 - Thursday, December 18, 1975. Procedures for filing complaints can be found in Federal Register, Vol. 42, No. 8 - Wednesday, January 12, 1977.

Typical of the "new generation" of mobile homes is manufactured by Guerdon Industries of Louisville, Kentucky. Figure 2 outlines the thermal standards of their homes.

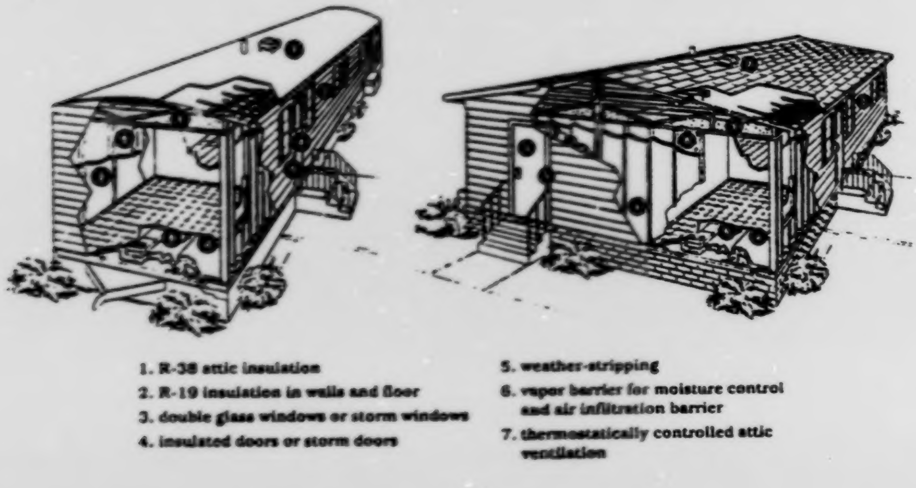

1. R-38 attic insulation
2. R-19 insulation in walls and floor
3. double glass windows or storm windows
4. insulated doors or storm doors
5. weather-stripping
6. vapor barrier for moisture control and air infiltration barrier
7. thermostatically controlled attic ventilation

Figure 2.

In a joint effort with Owens-Corning, the Arkansas Power and Light and the Arkansas State Energy Office, Guerdon tested their homes against homes constructed to meet FHA standards and HUD Title VI (mobile home standards) houses. The test involved three HUD houses, three FHA houses and four homes built to the standards above. Test results are reported to indicate that houses built to the above standards achieved savings of 59% over the HUD house and 49% over the FHA house.

Problem Specifics
What To Look For

Overview:

The assembly line construction techniques, lightweight/cheaper construction materials, and the need to transport the mobile home virtually guarantees certain energy problems with the mobile home. Workmanship often suffers as a result of the need to rapidly produce the low cost home. As a result, highway transport of the unit often causes cracks in seams, badly fitting doors and windows, and insulation sag or settling in the walls. Even when a vapor barrier has been installed, a common practice is to staple paneling directly to the wall studs. The result is thousands of tiny punctures in the vapor barrier.

The use of blocks as a foundation will cause shifting of the unit because of settling and frost heaves. Extreme temperature differences experienced in some areas may cause the steel girders on which the home is mounted to expand and contract. In interior Alaska, temperature variances can be as much as 150-170 degrees between winter lows and summer highs. Changes of 40-60 degrees in a matter of a few hours are not uncommon. This expansion/contraction can cause warpage of the wood members in the home, loosen joints and cause cracks in seams.

Another problem is that mobile homes have historically been built for sale within specific climatic regions. Being mobile, however, they often go with the owner when he/she moves to another location. Alaska has generally been considered a separate climatic region by itself and mobile homes built for sale here received somewhat more consideration. If, however, the mobile home was built and sold originally in California and then brought to Alaska with the owner, there is a real problem.

Infiltration

There are few existing measurements of infiltration/exfiltration characteristics of mobile homes. Those reports that do exist seem to contradict each other. One report states, "The unpartitioned mobile home appeared to be an extremely tight structure. The mobile home studied here seems to be typical of mobile homes in envelop tightness."[1] Another report says, "Mobile homes, especially older ones, are very leaky, i.e., they have high infiltration rates."[2]

The problem with both of these statements is that they have generalized that all mobile homes are the same, at least as regards infiltration characteristics. It is as easy to find a site built house that is tight or one that is leaky as it is a mobile home. One can not assume that just because it is a factory built home that it is a leaky sieve. Each individual structure must be examined for air leaks regardless of its type of construction.

There are some particular items to look for that may be indicative of being infiltration problems. In older mobile homes it was common to install jalousie and multiple-awning-type windows. By definition these window types have a much higher probability for air leaks. Even when cranked tightly closed an examination of each awning segment will probably reveal that some segments are not fully seated. To detect these problems may require going outside and pressing on the bottom of each segment.

If the mobile home is a double-wide unit or has an expanded unit there is a high potential for infiltration where the individual units come together. Siting crews have tendency to not seal these joints. Openings of 1" to 2 " have been reported in these areas.

Some mobile home manufacturers have installed hollow core doors as outside entrance doors. Besides being a source of high conductive heat loss these doors tend to warp considerably in cold climates. This warping will go away as outside temperatures warm up and the outside surface temperature approaches the inside surface. One would have to talk with someone who has lived in the unit during cold weather to substantiate this condition.

When considering infiltration in mobile homes it is always wise to find out how much and how far the home has been moved. If a mobile home has been moved several times over rough roads there is a good chance for leaks around windows and doors and for cracks in seams. If the home was pulled up the Alcan Highway, it should be a trigger for an energy inspector to look closely. Sometimes this can be determined by examining the manufacturer's specification plate. This may tell what zone in which the unit was built to be sold. If Zone 1 or Zone 11 is indicated, the unit was originally sold in the Lower 48 and was probably towed up the Alcan.

A couple of cautions may be in order relative to infiltration in mobile homes. First, it is common in older mobile homes for the furnace to use inside air for combustion. One should locate the combustion air duct and determine where the air is drawn from. If it is from inside the home, tightening the home too much could have adverse effects.

Secondly, tightening any home will add to moisture problems. The humidity level should be monitored to control this problem. There have been cases reported where mobile homes, built without proper vapor barriers, have been tightened up and had condensation in walls and ceiling destroy the small amount of insulation that previously existed.

The Envelope

Energy transfer by conduction through the walls, floors and ceilings of mobile homes is an obvious major concern. The enactment of standards by the State in 1972 with the subsequent HUD standards has helped with this problem. The low level set by standards for structural heat loss has not brought the mobile home up to the level of site built houses, in most cases. Mobile homes sold prior to 1972 must be very suspect of having inadequate insulation.

A 1981 model mobile home recently purchased in Anchorage contains a manufacturer's certificate proclaiming the following heat loss factors:

Flocr = U - 0.077 (R-13)
Walls = U - 0.077 (R-13)
Ceiling = U - 0.067 (R-15)

While these obviously exceed the HUD requirement of an overall U - 0.104 (R-9.6) they are no where near requirements of some local building codes for site built houses that require ceilings to be R-30 and walls to be R-19. In addition it is not known how the "U" values were derived by the mobile home manufacturer.

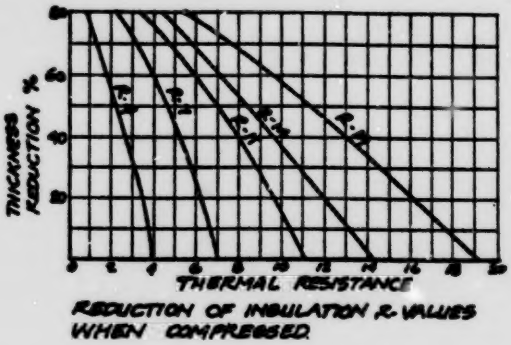
If the manufacturer simply added the "R" values of the building materials and insulation and dividing this into "1" (U=1/R) then the actual "U" values will be somewhat higher. This method of determining "U" values does not consider heat loss through the wood members. If this method were used the figures might add up like this:

Air Film = R-0.61
Paneling = R-0.93
3½" F.G. = R-11.00
Siding = R-0.61

Total R-Value = R-13.15 or U-0.076

When the heat loss through the wood members is considered, however, the overall R value for this wall might be closer to an R-10 or U-0.100.

Another point that is ignored in the above calculation is the compaction of the fiberglass insulation that is common in mobile home construction. In some areas of the construction the fiberglass is deliberately compacted to conform to tight joints and frame profile. When this is done the fiberglass is reduced in its effectiveness as an insulator. The amount of this reduction is demonstrated in Figure 3.



REDUCTION OF INSULATION R-VALUES WHEN COMPRESSED

Figure 3.

Another problem with mobile home walls was reported in one study[3] which is apparently prevalent particularly in older mobile homes. As reported, studies of mobile homes, including an analysis using infrared photography, revealed that a primary area of heat loss was convection loops in the walls resulting from wrinkling or settling of the fiberglass batt insulation.

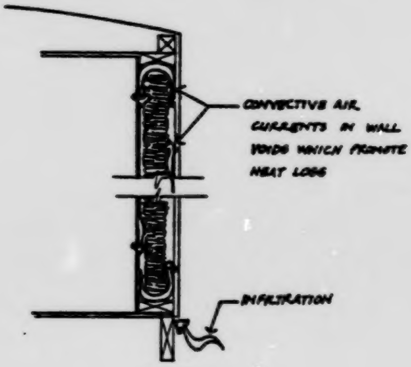

CONVECTIVE AIR CURRENTS IN WALL VOIDS WHICH PROMOTE HEAT LOSS
INFILTRATION

Figure 4.

Skirting is an area that should be examined in mobile homes. In a recently published report on heat loss through buffer spaces[4] it was reported that well-insulated skirting will reduce the heat loss through the floor and skirting by approximately 50% (1041 BTUH vs. 2073 BTUH) over the same mobile home that is skirted but without insulation on the skirting. No attempt was made to compare an unskirted home with the skirted and insulated home. This, of course, would be proportional to the amount of insulation in the floor of the mobile home.

There are some circumstances where skirting should not be considered. One publication reports that high wind areas may be one of these situations.[5] However, the report concedes that with proper tie-downs this may be less of a problem. The same conditions that apply to site built houses would apply to mobile homes as relates to permafrost conditions found in many locations around Alaska. As a rule, if the home is located over permafrost one would insulate the floor of the home and leave the crawl space open to prevent the home from sinking or shifting.

Retro-Fit Options

Overview:

The decision to retro-fit a mobile home should be based on the same economic and social criteria as for any other dwelling. Much has been said and written about the need to consider the typical short life of factory built housing when deciding to retro-fit. This consideration is never mentioned when deciding to retro-fit site built housing. At least one entire document[2] is devoted to the negative aspects of retro-fitting mobile homes. Referring to mobile homes as an "enigma" to document, the report says that there are "real questions about the values or usefulness of mobile home weatherization."

Experiments conducted and reported prior to the above publication do not support this contention, however. Experiments conducted by Oak Ridge National Laboratory[6] reported that the addition of retrofit items such as storm windows, skirting, and extra insulation can result in energy savings approaching 50% relative to heating a mobile home. This would have to be considered a significant reduction in energy usage.

Besides economic considerations, one must also consider social issues. Since mobile homes provide the bulk of low cost housing available, mobile home dwellers are typically those who can least afford high energy costs. Federal and State programs that provide subsidies for weatherization type programs are normally geared to low income families. It, therefore, follows that weatherization of mobile homes becomes a necessary objective.

One must also consider the responsibility of each of us regarding his/her role in reducing the overall demand for non-renewable energy sources. Retrofitting mobile homes would appear to provide an excellent opportunity to contribute toward this goal.

The argument that the anticipated life of the mobile home should exclude retrofitting does not appear entirely valid either. The very act of retrofitting may result in extending the useful life of the unit significantly. Problems that may result in the deterioration of the unit can be identified and corrected. This, of course, would have a two-fold effect on our energy situation. First, the energy saved from heating the unit and, second, the energy saved from not having to build a replacement unit. Just as with site built housing, there are undoubtedly mobile homes that should not be weatherized. The decision should not be based solely on a prejudiced presumption, however.

Some retrofit measures must be approached with some caution. There are some characteristics unique to mobile homes that must be considered. These relate to the basic construction methods used by some manufacturers.

In older mobile homes, those sold in Alaska prior to the State standards in 1972, may have been designed and built with a wall problem. Where 2 x 2 lumber was used for wall studs, the skin of the unit may be load bearing. Under some conditions, removing the skin (either the paneling or the siding) from the wall could have undesirable results. Newer units are being built, generally, either with 2 x 4 studs or with 2 x 3 studs coupled with 1 x 1 horizontal cross nailers and the skin is not relied on to support the roof.

Roof construction is another problem in older mobile homes. Quite often these are not built to support the weight of a human being. In any case, the metallic roofing common to mobile homes should not be stepped upon between the joists. Care must also be taken not to break the seal where the sections of metal roofing join.

Wall Retrofits

The basic retrofit decision in evaluating for wall insulation retrofits is whether to insulate from the inside or from the outside. There are advantages and disadvantages to each method. Insulating from the inside has the advantages of perhaps being easier to remove the paneling, not requiring protection from the weather during retrofit, allowing for the replacement of the paneling with sheetrock, and allows for installation of a vapor barrier if none currently exists. It has the disadvantages of being inconvenient to the occupant and destroying an existing vapor barrier. Insulating from the outside results in an increased effectiveness, is more convenient, and will allow for repair of holes and fractures that may be allowing moisture to penetrate the wall. Disadvantages would include the need to protect against weather while the skin is removed, difficulty in removing and replacing this metal siding, and the possible need to provide venting.

William Palmer, in his mobile home newsletter, "The Energy Hotline," reports that walls should be insulated from the outside. Mr. Palmer's source estimates that two competent servicemen can remove the outside skin of a 14' x 70' unit, fir out the studs, add insulation, cover with foam-core sheathing and replace the original skin in two days. This would include removing and replacing all windows, building out door frames, capping the corners, roof edges and bottoms with new added aluminum.

Two added thoughts on adding insulation to the walls in this manner. First, when the skin is removed it offers an excellent opportunity to do other things. One will be able to evaluate the condition of the existing insulation and the structural components. Replacement or shoring up of some studs might be indicated. One could also take this opportunity to replace a lot of dangerous aluminum electrical wiring that was used in older mobile homes.

The second thought relates to moving the mobile home later. Retrofitting from the outside will add several inches to the width of the unit and may make it too wide to transport over the highway system.

Once the decision has been made to reinsulate the walls, the next step would be to identify the type of insulation to be used. In addition to the four basic insulation types (batt insulation, poured or blown insulation, foamed-in-place insulation, and rigid board insulation) there are a number of non-standards insulating systems that should be considered. The following discussion will examine both the standard and non-standard systems.

Batt Insulation

Fiberglass batt insulation is commonly used in mobile home construction, primarily because it is low in cost, lightweight, and easily installed. However, it may not be the best insulation for use in mobile homes due to its vulnerability to moisture degradation. In order to achieve good thermal performance, batt insulation must be installed carefully, and great care must be given to weatherizing the mobile home exterior envelope.

If batt insulation is to be used the width used should completely fill the stud spacing. The proper installation procedure is as follows for installation from inside the home:

1. Fit the batt in between the studs, with the foil side facing the "warm-in-winter" side of the wall. Try to minimize any compression of the batt.
2. Carefully staple the flanged foil edges to the long side of the studs.
3. Tape over the stapled foil/stud interface to prevent passage of moisture through the interface into the wall cavity.

Installing batt insulation in this manner will minimize the possibility of settling or compacting, and the foil facing will act as a vapor barrier. If installation is done from the outside, batts without the facing (sometimes called friction fit) would be used.

Poured or Blown-In Insulations

Cellulose, rock or slag wood and fiberglass are commonly-used materials in this type of application. Their popularity in retrofit applications is attributable to their low cost and ease of installation, since the entire interior paneling (or exterior siding) does not have to be removed and re-installed. However, these materials exhibit many of the same undesirable features as batt insulation, sometimes to a higher degree. These include:

1. Settling and compaction
2. Moisture degradation
3. Low R-value per unit thickness

In addition, special equipment must be used for installing blow-in insulation. When used in ceiling cavity retrofit applications, the interior ceiling may require support to prevent damage due to the slight pressurization of the cavity from the blowing equipment.

In general, poured insulations of this nature are not suitable for wall applications due to extensive settling which will occur.

Foamed-In-Place Insulations

There are two basic types of foamed-in-place insulations; those that are fluorocarbon-blown materials (urethane and polyisocyanurate) and those that are air-blown urea-based materials such as urea formaldehyde. In general, these products have a high thermal resistance per inch but are also expensive to install. Because the materials are usually mixed at the site, the quality of application is highly dependent on the installer. The installation of these products requires special equipment and normally requires removal of the interior paneling. In heavier wall constructions, the insulation may be foamed in place without removal of the paneling; however, this technique is not suitable in mobile home retrofits due to the lightweight construction of the ceiling and wall assemblies. At least one attempt at using this technique in mobile home retrofitting resulted in considerable damage (caused by the foam forcing its way through the interior paneling and damaging interior furnishings).

Moisture released in the curing process can also migrate to other areas (such as the ceiling cavity), where it may cause damage to existing batt or loose-fill insulations if proper air venting is not provided.

Foamed-in-place insulation does require fire protection, and does not degrade appreciably due to moisture. The fluorocarbon-blown insulations do degrade in thermal resistance over time, due to the escape of the fluorocarbon gas (which is replacing by air that has a lower insulation value). The original R-value of fluorocarbon-blown insulation is generally about R-8 per inch, the accepted long-term R-value is approximately R-5 per inch.

Urea-based air blown insulations such as urea formaldehyde have an original R-value of about R-4 per inch, but the accepted long term value is closer to R-3. Urea formaldehyde is currently being studied to determine potential health hazards due to the escape of formaldehyde gas, which may cause nausea, dizziness, rashes and eye irritation. Although the release of formaldehyde gas is usually noticeable for only a day or two following the installation, current studies are being conducted to determine if it does in fact present any long-term health hazards.

Another problem with foamed-in-place insulation is shrinkage. The foam will shrink with age and has been known to create air gaps along studs when this occurs.

The recommended procedure for installing any foamed-in-place insulation is as follows:

1. Remove interior paneling, vapor barrier and existing insulation.
2. Caulk all gaps in the exterior siding liberally, to seal any potential sources of air infiltration and moisture penetration.
3. Blow the insulation into the wall cavity through a plywood jig temporarily attached to the studs.
4. Once the recommended time interval is reached, remove the plywood jig and proceed to the next stud cavity using the same procedures.
5. Once the insulation has cured, caulk any gaps or cracks that form due to shrinkage of the insulation during the curing process.
6. Install a new vapor barrier and replace the interior paneling (NOTE: If existing paneling is not fire-resistant, replace with 1/2" fire-resistant gypsum board or other suitable material).

Rigid Board Insulations

Typical rigid board insulation materials include extruded and expanded polystyrene, as well as composite "sandwich" boards with urethane or polyisocyanurate foam cores. They are characterized by medium to high thermal resistance per inch, and medium to high cost of installation. Rigid board insulations generally require a fire-resistant interior paneling, provide fairly good infiltration control, and are not susceptible to moisture degradation. Characteristics of each type of board insulation are described below:

1. Extruded Polystyrene

   This type of board insulation is manufactured using an extrusion process which entrains a mixture of air and fluorocarbons in the closed cell polystyrene material. The aged value of thermal resistance for extruded polystyrene varies with its density, with R-5.4 being typical for the most commonly used board of 2.4 pounds/cubic foot density.

Extruded polystyrene boards are available in tongue and groove construction (Styrofoam TG by Dow Chemical), which greatly enhances its value as an infiltration barrier. The compressed cell structure at the surface of the board (resulting from the extrusion process) aids in the prevention of the escape of the entrapped fluorocarbon gas. Zonolite Thermo-Stud is another commonly used extruded polystyrene product.

2. Expanded Polystyrene

Expanded polystyrene is manufactured via a molding process, which entrains air molecules in the cell structure. Expanded or molded polystyrene typically has an aged thermal resistance of R-3.6 per inch.

The higher thermal resistance of extruded polystyrene is due to the entrainment of the fluorcarbon gas/air mixture in the cell structure, which has a higher insulating value than that of air alone (which is used in the manufacture of expanded polystyrene).

3. Urethane and Polyisocyanurate Sandwich Boards

This type of insulation board is composed of a foam core "sandwiched" by layers of heavy paper or foil. The outside layers are provided to prevent the escape of fluorocarbon gases entrained in foam, thereby avoiding a reduction in the aged thermal resistance due to out-gassing of the fluorocarbons. A secondary benefit achieved through the use of these exterior layers is the additional infiltration and vapor barrier qualities of the dense foil material.

These rigid board insulations provide a high thermal resistance per inch (R-6 and R-7), but are also more expensive and require the use of fire-resistant interior paneling.

Commonly used products of this nature include Celotex Corporation's "Thermax" and Owens-Corning's "High-R Sheathing" which is a polyisocyanurate sandwich board insulation.

NONSTANDARD INSULATION MATERIALS

In addition to the standard insulation materials described, several new products are available which may be particularly suited to mobile home envelope retrofits. A discussion of each of these products is presented below.

Infra-Foil

This insulation type obtains high thermal resistance values from the use of parallel air spaces separated by a reflective foil/kraft paper laminate. R-values between R-7 and R-31 can be achieved depending upon the number of reflective air spaces specified and the particular application (the thermal resistance of reflective air spaces depends upon the direction of heat flow and whether the air space is in a vertical or horizontal plane).

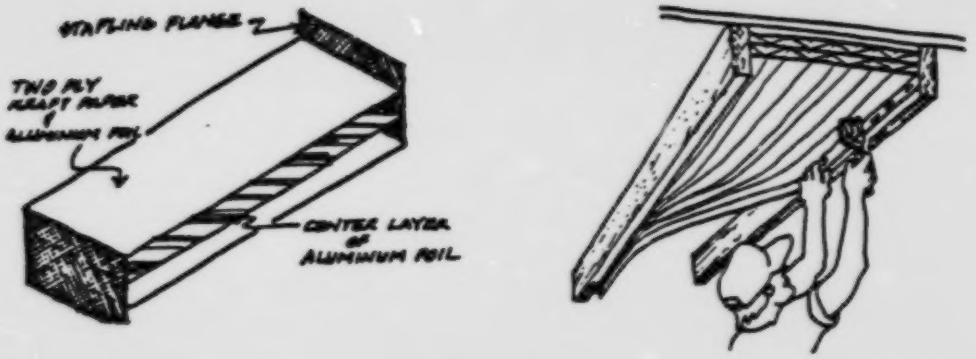

STAPLING FLANGE
TWO PLY KRAFT PAPER & ALUMINUM FOIL
CENTER LAYER OF ALUMINUM FOIL

Figure 5.

Infra-foil is very inexpensive, and easy to install (See Figure 5). The position of the stapling flanges ensures that an extra air space is created between the infra-foil and the interior/exterior surface of the wall or ceiling construction. Once stapled in place, the infra-foil flanges should be taped; due to the high density of the foil laminates, it can also act as an infiltration and vapor barrier. Infra-foil is also listed by the NFPA as a Class A fire-retardant. Shipping and handling of this product are facilitated by its lightweight construction and the fact that it is flattened for shipping, then expanded for installation. Care should be taken to avoid degrading the reflective property of the foil due to exposure to construction dirt.

Insul-Safe and "Macrospheres"

These two loose-fill insulation products are made up of tiny air-filled spheres of fiberglass. Although installation does require special blowing equipment, the rigidity of the tiny spheres avoids the "settling" problems associated with other blown-in insulation types. Because the spheres are composed of fiberglass, these insulations do not require fire-resistant interior paneling.

Insul-Safe insulation has a thermal resistance of R-3.6 per inch, while 3M Company's "Macrospheres" are rated at approximately R-3 per inch thickness.

Aluminum Insulating Wall Systems

Various aluminum insulating siding products are available, such as Alsco Anaconda's "Bak-R-Foam", illustrated in Figure 6. This type of product combines the longevity and ease of maintenance associated with aluminum and the insulating value of expanded polystyrene foam.

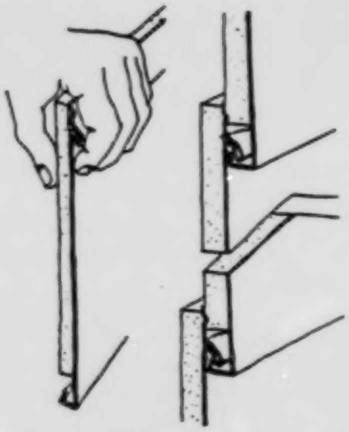


Figure 6.

The design of these products usually include two important considerations: (1) a thermal break between the aluminum siding and interior wall construction, and (2) an integral moisture vent that relieves moisture accumulated in the wall cavity.

"Dryvit" Exterior Wall Insulation System

Dryvit insulation is designed for use as an exterior insulation system for wall retrofits. This product consists of a four part lamination of expanded polystyrene board insulation, a reinforcing mesh of treated fiberglass, an adhesive cementitious plaster and a synthetic plaster exterior finish (see Figure 7).

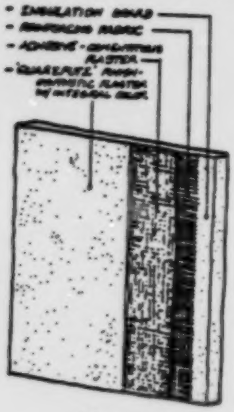


Figure 7.

This insulation/exterior wall system can be installed in the field, and is fairly easy to work with in "custom-fit" applications. Replacement of the exterior siding is not required, and the Dryvit wall system provides very good infiltration control.

Infiltration Barriers/Exterior Sheathing

The role of the infiltration barrier is particularly important in mobile home retrofitting, due to the potentially high infiltration load common to this type of construction. The most effective location for an infiltration barrier is at the exterior surface, although it may be located near the interior surface (for economic reasons) when an insulation which exhibits integral infiltration control is retrofitted from the inside.

When the infiltration barrier is located near the exterior of the wall/roof construction, it is best to utilize one which has a permeability rating of at least 5 perms/inch (permeability is the ability of a substance to "breathe" water vapor, with one perm/inch equal to 1 grain moisture/hour-sq. ft.-in HG). Infiltration barriers with high permeability ratings, therefore, have the capability of relieving accumulated moisture from the wall construction without using vents, which may induce undesirable convection currents within the wall cavity.

Infiltration control is often provided by applying exterior sheathing immediately inside the mobile home exterior metal siding. In selecting an exterior sheathing, it is desirable to consider one which provides good infiltration control and a permeability of 5 perms/inch or more. If it also provides some insulating value its benefits are three-fold; however, there are always economic trade-offs to consider. The following discussion summarizes the types of infiltration barriers available and their characteristics. Figure 8 provides a summary of the characteristics of various materials commonly used as exterior sheathing/infiltration barriers.

Plywood Sheathing

Thin sheets of plywood are commonly used in conventional construction as an exterior sheathing; however, it exhibits a very low permeability (approximately 0.7 perms/inch) and, therefore, requires that the wall cavity be vented. It also has very little value as an insulation, and is more expensive than other available materials.

Asphalt Building Paper

Asphalt building paper, when certified with a permeability rating of 5 perms/inch or greater, can provide good infiltration control without requiring venting of the wall cavity. It is fairly inexpensive and commonly used in conventional construction.

EXTERIOR SHEATHING/ INFILTRATION BARRIERS	APPROX. 1980 RETAIL MATERIAL COSTS (R/Sq.Ft./Inch)	R-VALUE FOR THICKNESS LISTED	DEGREE OF INFILTRATION CONTROL PROVIDED	WATER VAPOR PERMEABILITY, PERMS/ INCH	COMMENTS
1/4" Plywood Sheathing	$0.10±	0.25	Fair	0.7	Effectiveness as infiltration barrier depends on proper installation (taping/sealing required).
3/8" Fiberboard Sheathing	$0.12±	1.02	Fair	27.7	Effectiveness as infiltration barrier depends on proper installation (taping/sealing required).
1" Fiberglass Insulated Sheathing	$0.28	4.4	Fair	High	Effectiveness as infiltration barrier depends on proper installation (taping/sealing required).
1/4" Foam-Cor Insulated Sheathing	$0.13	1.03	Excellent	8.8	Available in continuous sheets, folded accordion style for shipping.
Dupon Tyveck Polyfilm	$0.04	n/a	Excellent	High	Least costly infiltration barrier, use in conjunction with insulation retrofit.

Figure 8.

Tyvek

Tyvek is a polyfilm infiltration barrier produced by DuPont. It is very low in cost (3 to 4 cents per square foot) and easy to apply. It has a high permeability rating and can provide a continuous infiltration barrier around the entire perimeter of a mobile home.

Fiberboard Sheathing

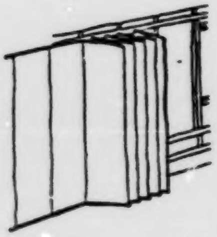
Fiberboard 3/8" sheathing is also a commonly used exterior sheathing which has a high permeability rating (more than 27 perms/inch). However, careful installation is required to obtain good infiltration control. After it is nailed in place, all joints and cracks should be carefully taped and sealed. It is fairly high in cost (approximately 12 cents/sq. ft.), but does add some rigidity to the exterior metal siding.

Fiberglass Sheathing

Fiberglass sheathing, a product of Owens-Corning, provides infiltration control and additional insulation value due to its construction. Available in 1" thickness, this exterior sheathing board is composed of fiberglass insulation "sandwiched" between a vapor permeable facing. The thermal resistance of the 1" board is R-4.4, and it has a permeability rating of greater than 30 perms/inch. The installation procedure should include taping and sealing of all cracks and gaps. The cost of this material is higher than non-insulated sheathing materials, and is approximately 28 cents per square foot.

Fome-Cor Insulated Sheathing

Fome-Cor, a product of the Monsanto Corporation, is a continuous 1/4" thick sheathing material composed of polstyrene insulation sandwiched between two layers of kraft paper facing. It is manufactured in seamless sheets, then scored and folded accordion style for shipping and installation (See Figure 9).



FOME-COR INSTALLATION
ON EXTERIOR WALLS

Figure 9.

Because it can be installed as a continuous sheet, Fome-Cor provides very good infiltration control and also adds a thermal resistance of R-1.04 to the wall/roof assembly. It has a permeability rating of approximately 9 perms/inch. It is available through mobile home dealers who specify it for new mobile homes. Because polystyrene is used as the insulation, a fire-resistant interior paneling is required.

Rigid Board Insulations

When applied to the exterior side of the wall construction, rigid board insulation can be used to provide good infiltration control. Unless a rigid board insulation available in tongue and groove construction (such as Styrofoam TG polystyrene) is used, the installation procedure should include taping and sealing of all joints and cracks. However, most rigid board insulations do not have high permeability ratings and, therefore, require venting of the wall cavity. Also, fire-resistant interior finish material is usually required when rigid board insulation is used.

Roof Retrofits

When deciding on a solution to retrofitting the roof insulation one must bear in mind the risk of subsequent damage to roof leaks. Because the metal covering is usually very thin and often supported only at long intervals by framing members simply stepping on the roof at an unsupported spot can cause damage and leaks to occur.

Removing the exterior roof covering may not present major problems; however, replacing it and realigning the fasteners may amount to an impossible task. For this reason, retrofitting the roof with an insulation/moisture proof material that does not require removal of the existing roof, is highly desirable.

If little or no insulation exists in the ceiling cavity, blown-in insulation can be used to provide some measure of relief. Depending on the framing that was used, this may result in only minimal thermal protection, however.

Although the use of blown-in cellulose is common in mobile home roof insulation retrofits, this application technique may result in the following problems:

1. Degradation of insulation value due to compression and water damage caused by roof leaks.

2. Complete filling of the roof/ceiling cavity with cellulose will block the cavity vents and prevent attic air circulation which is required to remove accumulated moisture.

Foamed-In-Place Insulation

Many Alaskan mobile home owners have attempted to solve the roof insulation problem by having their roof covered with urethane foamed-in-place insulation. The high R-value of this material makes it an attractive alternative. It does have several disadvantages, however, which include:

1. Urethane is a flammable material.

2. Generally the application is not very even which results in a roof looking like rolling foothills.

3. It must be sealed and covered with a material to protect it from virtually complete degradation.

"Thermo-Ann" Roof Insulation

This product is a flexible insulated roof insulation which shows good potential for mobile home exterior roof retrofit applications. It is composed of a white Hypalon membrane outer surface combined with fiberglass commercial grade duct insulation. Hypalon membranes are commonly used as waterproof liners for man-made reservoirs, and are seeing increasing use in commercial/industrial roofing systems. Fiberglass duct insulation is used in lieu of fiberglass batt insulation because of its better resistance to compression forces which would reduce its insulating value.

The primary advantage of utilizing this type of roof insulation is that it is applied to the exterior of the existing roof. Its excellent waterproofing properties reduce the risk of subsequent rain leakage for which the installer may be liable. This product is manufactured by Thermo-Ann Industries, Inc., Phoenix, Arizona, and is marketed in Alaska and available in various thicknesses of insulation. It was specifically designed for mobile home retrofitting, and test results from many mobile home installations are available. The Municipality of Anchorage retrofitted a number of mobile homes using this insulation but, to date, no firm results of its effectiveness have been determined. Most test results deal with it as an effective insulator in an air conditioning situation but the effect of compression resulting from heavy snow loads is not as well documented.

Add-On-Roofs

Another technique seen employed by some Alaskans has been to frame a gabled roof over the top of the existing roof. The new roof is supported by posts running up the outside walls of the mobile home. Done in this manner virtually any amount of fiberglass insulation can be layed directly on the existing roof. One would suspect that this would be an expensive retrofit solution. However, if done as part of another project, such as adding a garage, it could be very feasible.

Skirting

Whether or not to skirt a mobile home, as well as the best way to accomplish it, has brought about some lively discussions at times. Generally, it appears that unless the home is setting on permafrost or is subject to extremely high winds along the long wall surface, then insulated skirting is advisable. In the Oak Ridge Tests[6] it was reported that a 12% heat, energy savings was achieved by adding skirting. In the Alaskan environment the technique of insulating skirting is often necessary to avoid freezing water and sewer lines.

Conventional Skirting

Conventional skirting is normally accomplished by building a wood frame under the outside walls of the mobile home. Insulation is then installed between the framing members and a sheathing attached to the outside of the framing.

There are a number of options for the outside sheathing material from which to chose. These range from fiberboard to plywood to steel and aluminum panels. It is popular to choose a material that coordinates with the siding on the mobile home.

When deciding on the type of insulation to use in the skirting effort there are a couple of considerations that are important. While rigid board insulation is the easiest to work with in this situation and provides the highest R-values per inch, it should be noted that it is flammable and some building codes require it to be covered with sheetrock or similar material when used in any wall. Also, some rigid board insulation will allow moisture to permeate upward through the board when stood up on moist earth. It is not uncommon to see this board swollen as much as 50% for several inches above the ground when it has been used for this purpose. When permeated with moisture it has questionable insulating values.

Fiberglass, on the other hand, will totally degradate when subjected to constant moisture. It is important to provide a visqueen barrier, therefore, between the insulation and the ground.

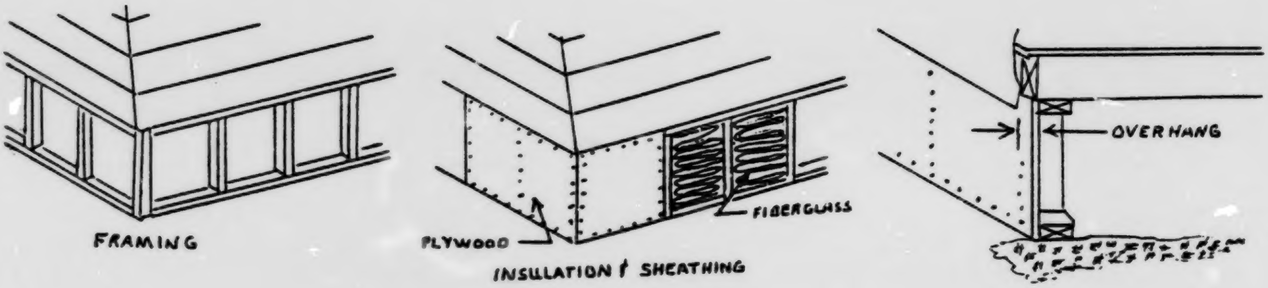


Figure 10.

When framing the skirting, the framework should be set back under the mobile home far enough so that when the sheathing is attached the outside wall of the mobile home will overcap the skirting. This will prevent water from running inside of the skirting when it rains.

Earth Mounding Skirting

One source [3] recommends earth mounding as a better alternative to conventional skirting. This is done by attaching an exterior grade plywood or planking against the underside of the steel framework with galvanized fasteners. To this substrate attach a heavy mil polyethelene moisture barrier and backfill with earth and provide a slight grade for drainage.

While this procedure would undeniably provide an effective barrier against infiltration and heat conduction, it has one basic problem. It does not permit the owner access to the underneath of the mobile home. In Alaska, where frozen pipes are often a way of life and the fact that the system quick drain is located under the unit makes this access vital. Perhaps an alternative would be earth mounding three sides and conventional skirting on the fourth.

Carlson's Skirting

Still another method of skirting and insulating has been advanced by Axel Carlson, Extension Engineer, University of Alaska, Fairbanks [7]. This method involves conventional uninsulated skirting with fiberglass insulation being placed on the ground and extended up the walls of the skirting in one continuous sheet. The fiberglass is protected from water vapor as well as surface water by wrapping it in 4 mil polyethelene. A tube is formed by wrapping the insulation (9 inch thickness recommended) in plastic that is run longitudinal to the insulation. The seams are folded over and sealed by a heavy duty stapler. The seams should be placed on the top of the insulation. The tube is laid perpendicular to the wall and hung by staples from the bottom of the mobile home wall.

This method would appear to be an answer to skirting/insulating over permafrost while still allowing access to the underside of the unit with only minimal trouble.

Skirting should be considered as an extension of the floor of the mobile home. Providing skirting, and insulating it, in effect adds insulation to the floor and will result in less heat loss from this area. It is perhaps the most cost effective improvement that can be made to some units in Alaska.

Floor Insulation

The decision to insulate the floor of the mobile home requires some careful thought and consideration. As mentioned above, the floor can be effectively insulated by insulated skirting. Since water and sewer distribution lines are normally present under the unit one must be careful to protect them from a harsh Alaskan winter. Floor insulation should only be added after proper protection of the water and sewer lines has been provided.

Still another important consideration in this area would be the floor of the crawl space. Paramount here would be the installation of a proper vapor barrier. If skirting of any kind is used, protection must be provided from ground moisture which will be drawn upward into the mobile home. It is extremely important that the floor of the crawl space be lined with a minimum 4 mil polyethelene which is overlapped to provide an effective vapor barrier. The vapor barrier can be covered with a thick layer of earth or held down with rocks, brick or any other material. This will greatly reduce the potential moisture damage to the unit and should even be noticeable in reducing condensation and icing on windows. In high moisture ground conditions a sump pump should be used in combination with the ground vapor barrier.

If insulating the floor of the mobile home is determined to be the best route to take, this is the easiest retrofit measure to accomplish. Fiberglass is simply secured between the floor joists. A friction fit fiberglass batt should be used and can be held in place by criss-crossing twine or wire or with a chicken wire mesh.

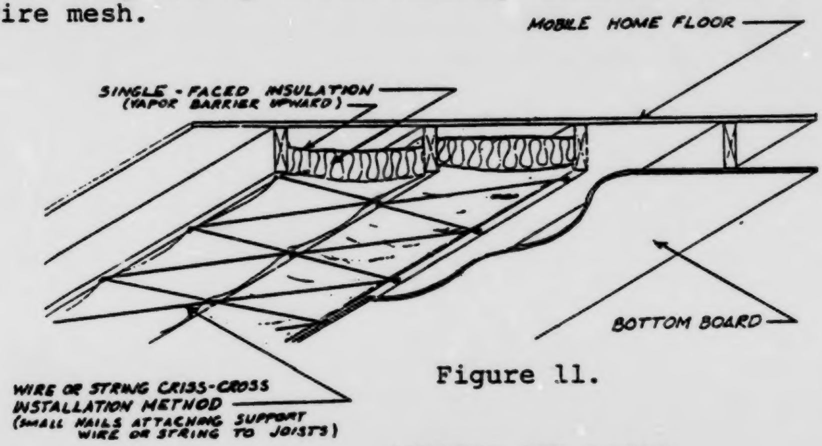

MOBILE HOME FLOOR
SINGLE - FACED INSULATION
(VAPOR BARRIER UPWARD)
BOTTOM BOARD
WIRE OR STRING CRISS-CROSS
INSTALLATION METHOD
(SMALL NAILS ATTACHING SUPPORT
WIRE OR STRING TO JOISTS)

Figure 11.

WINDOWS AND DOORS

Overview

Windows and doors in mobile homes offer one of the best areas for improvement. The general poor quality windows and doors used in construction of the units results in a major source of heat loss. This is particularly true in older units where jalousie or crank operated awning type windows were in common use. There is an even greater problem where moving the home or improper leveling has caused the windows to warp or fit improperly. Often, in older units, air gaps remain between the panels of glass even when they have been firmly cranked closed.

Newer mobile home models (those sold in Alaska since the implementation of State standards in 1972) are typically equipped with sliding panes and storm windows. These are generally better quality windows but suffer from a couple of major weaknesses. First, the practice of installing the storm window from the inside of the unit is not the best option in an arctic situation. These storm windows do not seal with the frame when closed. This allows moisture from inside the home to migrate to the outside pane of glass. Since the outside pane is insulated from the heat source by the storm window it is, for all purposes, at the outside temperature. Extreme frost and icing occurs then on the inside of that pane of glass in colder weather. As the weather warms the frost/ice melts and water damage can occur to the wood and wall insulation below the window.

A second problem with the mobile home window is the exclusive use of aluminum framings. Aluminum is an excellent conductor of heat and these frames provide a thermal bridge for an unbroken path of heat flow. The light weight and strength of the metal also makes them susceptible to stresses which will open gaps for further heat loss. This problem can be further aggravated when coupled with the condensation and icing problem noted above. If moisture finds a small crack, it will freeze and expand within that crack thereby widening it even more.

In their report, Burt Hill Kosar Rittleman Associates [3] make a strong case for replacing mobile home windows as a safety factor, as well. According to the NFPA, the chance of fatalities in a mobile home fire is six times greater than in conventional home fires. The intense heat, characteristic of mobile home fires, causes aluminum cased windows to warp and jam or become too hot to touch. In many cases the window may be the only escape available to the occupants. This fire hazard is very real in older mobile homes and is reason enough for the owner to consider replacing or improving existing windows.

Tests indicate that much can be done to improve the thermal performance of mobile home windows and doors. The Oak Ridge[6] tests reported an almost 9% heat, energy savings by adding storm windows to their test unit. Other tests prove significant savings. The following is a discussion of the issues involved and suggestions for both windows and doors.

Windows

There should be more stringent performance specifications for windows in new mobile home construction. The inclusion of double glazed windows by some manufacturers is an appropriate choice, assuming an effective seal at the window-to-wall interface. In mobile homes which have been moved, sited and occupied for any length of time, all windows should be carefully scrutinized for structural and thermal integrity. Taping the inside windows with a special low perm tape may be sufficient for eliminating condensation on the inside of the exterior primary window. The condensation problem is alleviated when the tape seals the inside window frame/paneling interface, a major element in the mobile home "pressure envelope". Even though masking or duct tape may be effective in other areas, they do not do a satisfactory job in an arctic situation. A clear cellophane tape is currently being marketed in Alaska that was developed specifically for this purpose. It should not be assumed that sealing the inside window will be a completely effective energy conservation measure, however. Infiltration allowed to penetrate the exterior primary window in a mobile home may find its way into the wall cavity surrounding the window opening, and the resulting heat losses can be substantial. The table in Figure 12 is a listing of problem areas treated in the air leakage experiments conducted by the National Bureau of Standards in their investigation of the Thermal Performance of a Two Bedroom Mobile Home. Under test conditions, the 18% reduction in air leakage as a result of sealing the inside windows was the largest total component. This is a test result only, as the actual conditions experienced by a mobile home in the field may vary substantially because of location, exposure, temperature, etc. However, in an old mobile home the values listed in the table may very well be conservative.

MOBILE-HOME FORCED AIR LEAKAGE CHARACTERISTICS, FT^3/MIN.

SEQUENCE OF SEALING	POTENTIAL LEAK LOCATION SEALED OR UNSEALED	RESIDUAL AIR LEAKAGE	REDUCTION DUE TO SEALING OF LEAK	SEQUENCE OF SEAL REMOVAL	INCREASED FLOW--SEAL REMOVED
1	Original Condition	1,020		13	1,039
2	Bathroom Ventilation Fan	869	151(14%)	11	156
3	Between Ceiling and Flue Vent	789	80(8%)	9	88
4	Lower Hinge Side of Rear Entrance Door	783	6(1%)	2	4
5	Two Plumbing Holes Through Floor	744	39(4%)	8	38
6	Duct System (register opening & blower return opening)	744		10	6
7	Wall Heater	716	28(3%)	7	36
8	All Exterior Outlets and Switches	699	17(2%)	5	19
9	Windows Sealed to Inside Surface of Wall Paneling	511	188(18%)	1	240
10	Front Base of Furnace	497	14(1%)	12	
11	Paneling Side Joints	420	77(8%)	4	76
12	Joint Between Wall and Ceiling	282	138(14%)	3	90
13	Furnace Room Door	275	7(1%)	6	

Figure 12.

It is apparent that an effective window retrofit for energy conservation in mobile homes must consider the entire window assembly as a unit, since either the exterior primary window or the interior storm window will only provide a partial answer to the problem of poor window performance in mobile homes.

There are some possible retrofit improvements to existing windows. First would be to perform routine maintenance on the existing window assemblies, including caulking all accessible seams with a non-hardening construction grade sealant, repairing and lubricating operable hardware, and adjusting it to provide the greatest degree of closure possible. Slide locks and key ways can be added to most window types to insure a tight window seal with a slight amount of compression. All framing between the primary and storm windows should be caulked or weatherstripped to prevent air from penetrating the wall cavity. An aggressive retrofit plan for existing windows would include exposing the perimeter of the interior and exterior window assemblies from inside the wall cavity by removing the interior wall covering, to reveal any additional air passageways that may be blocked or sealed for increased tightness.

Almost any effort expended to improve existing mobile home windows is worthwhile. The measures discussed here are inexpensive, effective and easily performed by the mobile home owner. However, they do not remedy the deficiencies inherent in the stock metal mobile home windows; therefore, a completely effective window retrofit would probably necessitate the substitution of a better quality, more thermally-efficient window unit. Replacement is not, however, an inexpensive solution, and achieving a reasonable payback period may be difficult. This is further complicated by the non-standard sizes of mobile home windows. Commercially manufactured units are not likely to be available.

The stud frame construction of mobile homes and the absence of any appreciable loading from multiple floors or heavy roof systems make altering the mobile home envelope a relatively simple task. Conventional carpentry skills are sufficient to remove existing doors and windows and to alter the rough openings as required to accept the replacement door or window units. The retrofit possibilities are limited only by the units available, the extent to which the occupants wish to improve their mobile home and the owner's willingness to incur expense.

To be successful, the window replacement should be evaluated for thermal characteristics and overall construction. The mechanism should be easy to operate, with air-tight sealing and resistance to warping in the event of fire. If emergency egress is a concern, the window should have a 20" clear opening as close to the floor as possible.

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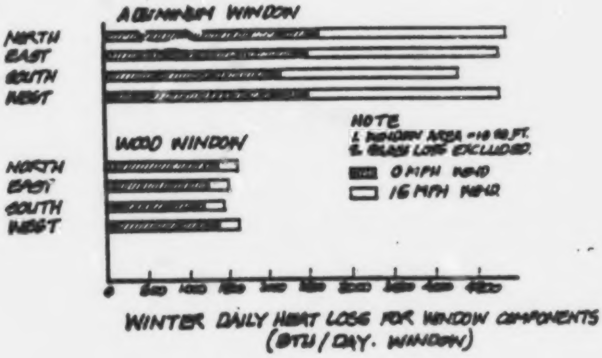

Figure 13.

Figure 13 shows the superiority of wood as a window (and door) frame material. Metals generally have an R value approaching "0" which means they offer no resistance to heat flow. The R value of wood or vinyl clad window frames may vary with design, but the effect is significantly better. Figure 14 shows a typical wood casement window retrofit. The current product lines of the major window manufacturers include numerous preassembled insulating window units which can be easily adapted to the mobile home frame construction with a minimum of finish carpentry or structural alternations. The mobile home owner can also take advantage of the installation templates supplied by these manufacturers as well as design services by sales representatives.

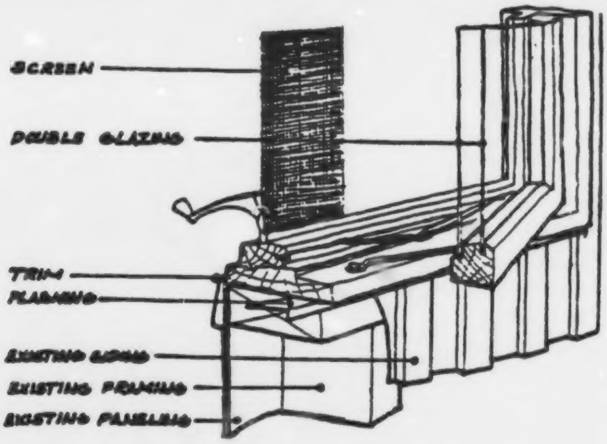

Figure 14.

Condensation - Storm Windows

Condensation in between windows is often the result of installation practices such as attaching the storm windows to the inside wall surface. Unfortunately, the seal between the inside storm window and the interior wall surface is seldom effective, so that warm conditioned air escapes and condenses on the inside of the exterior primary window; this is aggravated in mobile homes with vented wall cavities since cold outside air can penetrate the window assemblies and quickly cool the inside glass surfaces of storm windows, causing condensation. Under more severe test conditions, frost was reported on the outside face of the insulation in both the wall and roof. Sealing the inside storm window and venting the exterior primary window can alleviate the condensation on the inside surface of the exterior primary window, approximating conventional residential construction where the storm window is located on the outside.

Infiltration and moisture condensation problems inherent in mobile home window construction can be overcome by the use of storm windows, and they can be wise investments, especially in an Alaskan climate. It should be noted that storm windows, if installed outside, will amortize very quickly, an important consideration. Unless the retrofit being considered combines reasonable first cost and moderately high energy savings, it probably will not be considered desirable for all mobile home owners.

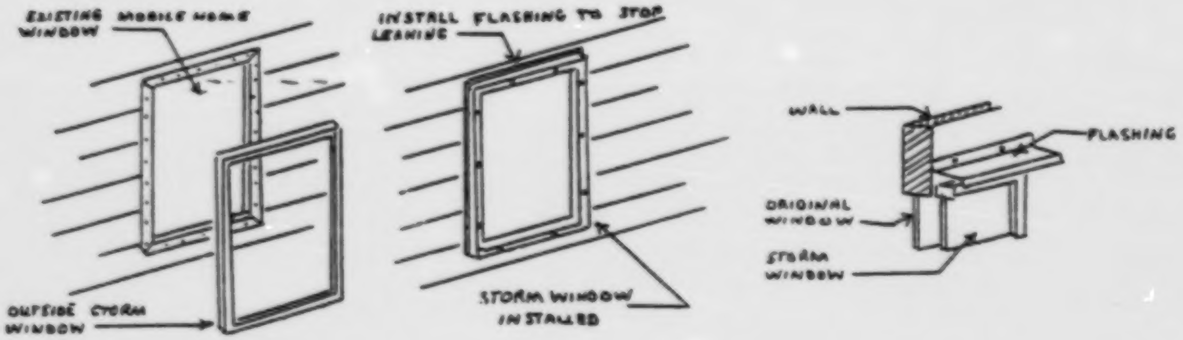

Figure 15.

The ideal solution would be to use good quality, wood frame, double-paned insulating glass windows which are operable, since they are far superior to the twin single glazed components most mobile home manufacturers offer as storm window systems. They have the further advantage of not needing to be removed to respond to temperature changes. A double glazed wood frame casement window commonly has a R value of 1.8 while a single glazed aluminum window, typically installed in mobile homes, has an average R value of less than 1.0.

Mobile home doors have many of the same deficiencies inherent in mobile home windows. Traditionally composed of aluminum frames with various core compositions or hollow core, the doors are chronic sources of heat loss, air and water infiltration into the mobile home interior.

Doors

Because of the proportionately small surface area of mobile home doors with respect to the rest of the envelope, heat loss or gain by conduction is generally ignored as a source of energy lost. If the home was built to Alaska standards, then infiltration is considered a more significant problem because of ill-fitting frames and hardware mentioned earlier.

Figure 16 shows the distribution of heat loss and heat gain for a 12' x 60' mobile home. It is apparent from these diagrams that infiltration is a major source of heat loss and heat gain in mobile homes. Weatherstripping of both doors and windows is important to counteract this air infiltration around the frames.

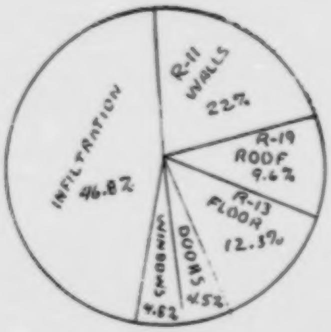

Figure 16.

Weatherstripping can be classified into three main groups: jambs, astragals, and sills. Each poses a different type of problem. The jamb, the vertical edge of a door or window, is one of the easiest areas to solve infiltration problems, since the primary concern is a seal which is unobstrusive, inexpensive and easy to install. The astragal is the vertical point where two movable doors or windows come together, requiring a solution similar to the jamb. The sill of the door requires something that can withstand the impact of foot traffic.

Weatherstripping can be broken down into the following types:

Interlock--Consists of interlocking strips of metal connected to both the jamb and the door. It is one of the best seals available if properly installed.

Spring Metal--If metal strips are correctly installed, they can be highly efficient. They come as flat "tension strips" sold in rolls. One edge of the strip is nailed to a door or window frame and the free edges then lifted away from the frame. The spring developed holds the strip of metal against the door when closed.

Gasket--A gasket consists of compressible tubing manufactured out of rubber or vinyl plastic tube with a flange for nailing to the door stops. The tubing is slightly compressed upon the door closing to create a seal. It can be non-reinforced or reinforced at the flange by an aluminum strip.

Felts--Felts are not quite as compressible as gaskets and come in a variety of materials. All-wool felt is preferable; it can be obtained in reinforced and non-reinforced types.

Foam Strips--Usually made of a synthetic material, foam strips come in rolls of various widths and thicknesses. They can be applied in a variety of methods. Some are glued on, usually by means of pre-applied adhesive protected by a peel-away paper covering.

Unfortunately, weatherstripping an existing mobile home door will be only marginally successful if the door frame is subject to racking. Many metal weatherstripping systems when used with metal doors are only partially effective because of their tendency to conduct heat through the door or door frame assembly. Condensation, prevalent in mobile homes for reasons described earlier, can also occur around doors using metal weatherstripping; in cold weather this condensation freezes.

Mobile home owners interested in upgrading their entrance ways for safety, energy conservation or aesthetics should consider completely replacing the standard mobile home door. Rough openings for doors can be reworked easily in mobile homes because of the sturdy frame construction, and removing the existing door provides the additional opportunity to reinforce the door openings against warping or binding. Side frame members and headers can be doubled or braced with metal plates if additional rigidity is desired. The substitution of a wood door frame assembly can eliminate many of the problems of condensation, infiltration, thermal performance and safety mentioned previously. This reworking also offers the opportunity to foam in insulations which can reduce or eliminate air infiltration around the door frame assembly.

A number of stock door replacements are available to the mobile home owner; the possibilities are limited only by the amount of capital the owner wishes to invest and the end result desired.

Figure 17 illustrates a typical prepackaged insulating entrance door assembly. Of particular interest are the energy features dealing specifically with infiltration and heat conduction. The inclusion of the frame component, hinges and hardware make packaged door retrofits particularly attractive. The ability to adjust sill heights and select door swing direction further simplifies installation. Door systems of this type also offer improved security and wide clearances for the elderly or handicapped.

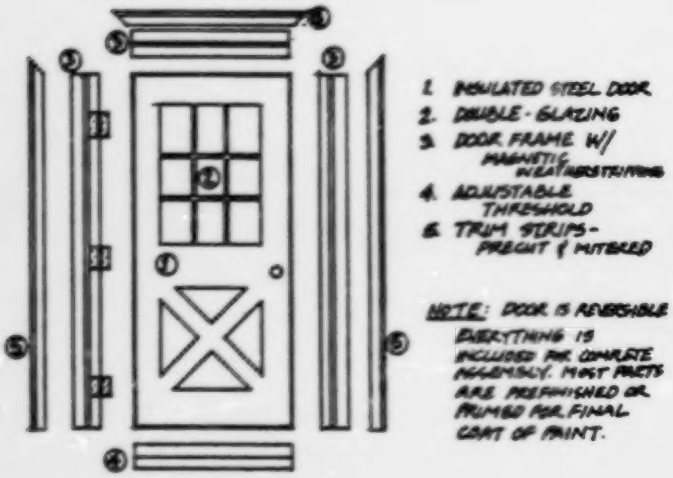
1. INSULATED STEEL DOOR
2. DOUBLE-GLAZING
3. DOOR FRAME W/ MAGNETIC WEATHERSTRIPPING
4. ADJUSTABLE THRESHOLD
5. TRIM STRIPS- PRECUT & MITERED
NOTE: DOOR IS REVERSIBLE
EVERYTHING IS INCLUDED FOR COMPLETE ASSEMBLY. MOST PARTS ARE PREFINISHED OR PRIMED FOR FINAL COAT OF PAINT.
1
2
3
3
4
5
5
5
5

Figure 17.

Storm doors serve the same purpose as storm windows and are viable options in virtually every area within Alaska. These are readily available commercially in a variety of sizes and are easily installed. Putting a storm door on the outside of a standard solid core door results in about a 20% savings from conductive heat loss through the door. Actual savings will probably be more than that since proper installation of the storm door will also reduce loss from infiltration. Wood storm doors are generally more effective than aluminum doors but are considerably more expensive.

MISCELLANEOUS ITEMS TO LOOK FOR

Bathroom Exhaust Fans

Although a relatively small opening, the fan is a direct path to the exterior, usually without benefit of a back draft damper or manual closing device. This writer has been in mobile home bathrooms where one could clearly see outside when looking upward through the vent fan. A warm spell, immediately following a heavy snowfall, resulted in the melting snow dripping back down the vent opening into the bathroom. Fortunately, in many units this problem can be effectively alleviated. The opening should be fitted with a plate or hinged door that will resist wind suction and eliminate air movement in either direction. One such method would be a plate that attaches, magnetically, to the vent flange from inside the bathroom, as demonstrated in Figure 18.

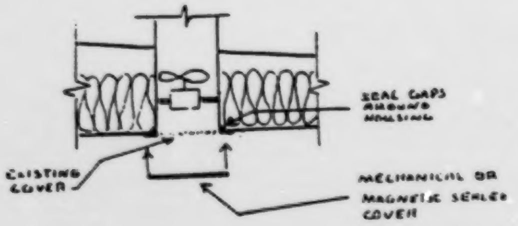

Figure 18.

Electrical Outlets

Even with site built houses, the space behind electrical switches and outlets in outside walls does not allow for proper insulation. This is an area that cannot be covered with a vapor barrier. Consequently, there are problems with both conductive and infiltration heat losses. Both of these problems can be easily improved, however. Commercially available polystyrene outlet gaskets can be installed behind the face plate cover of the switch or outlet. To further reduce infiltration in unused outlets, use a dummy plug, such as one used to child proof outlets.

Hot Water Tanks

It is normal practice for mobile home builders to put hot water tanks in small rooms that are accessible only from outside the unit. Typically the door of this room is insulated even less than the wall of the mobile home. The door could be reinsulated by several methods to improve the condition. Since the hot water tank is a major source of mobile home fires, any flammable insulation should be avoided for this purpose. Care should be taken with gas type hot water tanks not to tighten up this room to the point of eliminating combustion air.

Turn down the thermostat setting on the hot water tank. This is an absolutely cost free action. Measure the temperature of the hot water coming out of the tap. It should not exceed 140 degrees if you use a dishwasher or 120 degrees if you don't use a dishwasher. A good estimate of the dollar savings that can be achieved is about 1% for every two degrees of thermostat reduction. For example, if the thermostat is turned down from 165 degrees to 120 degrees (45 degree reduction) a savings of 22½% of hot water costs will be achieved. A secondary benefit from reducing hot water temperature is a safety factor. Many children, and adults, receive serious burns from hot water coming out of the faucet each year. While turning down the thermostat may not totally eliminate this problem it becomes less likely or serious at 120 degrees than at 165 degrees. Quick recovery electric tanks have two thermostats, one at the top and one at the bottom of the tank. Both must be adjusted to achieve the desired result.

Insulate hot water tanks and piping. The Department of Energy suggests that over two million BTUs of energy are lost from an improperly insulated hot water tank each year. Insulating kits are available from many commercial sources for water heaters as well as pipe insulation.

Ironwork

The mobile home is normally built on a steel frame. The floor of the unit is built upon this frame. Often, even if some insulation is provided in the floor, these metal beams are left exposed and provide a good path for heat transfer. Even worse is when the heating ducts pass close to this metalwork. These metal beams should, then, be insulated themselves. Fiberglass can be used for this purpose in most cases.

The Furnace

Furnaces are typically grossly oversized. In most cases, furnaces in all homes (site built as well as mobile homes) have at least twice the heating capacity required to do the job. From personal experience, this writer more than doubled the conditioned area of a 14' x 70' mobile home (added an 8' x 20' extension to the side of the unit, then put in a full daylight basement) without changing the furnace. With an unofficial outside temperature of -72°F the furnace maintained an indoor temperature of +70°F by operating 80%-85% of the time.

The constant on-off cycling of the furnace wastes considerable heat. The heat exchanger, as well as other metal components, are heated each time the furnace comes on to a high temperature. When the circulating fan quits, all of this heat escapes up the flue. The more oversized the furnace is the more often cycling occurs. Ideally the furnace sould be sized to operate 24 hours per day on the coldest day of the year. Realistically one is never going to know what temperature that is.

Virtually all furnaces can be derated, however. This is particularly true if the mobile home owner accomplishes the structural retrofits that have been recommended. This is a relatively simple and inexpensive task involving installation of smaller orifices and air intake restrictors. It should only be done by qualified furnace maintenance people, however. A good furnace repairman should be able to tell a mobile home owner which size orifice would be best based on the existing furnace size, type and climate involved.

Clock Thermostats

Setting back the thermostat at night and during periods when the home is unoccupied does save energy and heating costs. This is particularly true in a mobile home where there is little thermal mass involved. There is not large masses to reheat as a result of lower thermostat setting. Clock thermostats work best for this effort since they can be programmed in advance and then forgotten. It is estimated[8] that a 10 percent savings in heating costs can be achieved with a 10 degree set back for eight hours per day.

When considering temperature control in the Alaskan environment some care must be exercised. Turning down the thermostat too low can lead to negative results. Since plumbing and sewer lines generally run through the crawl space beneath the mobile home and rely on heat loss from ducting and through the floor of the home to keep from freezing, too low of a thermostat setting may cause the pipes to freeze. Another consideration is the outside walls. Setting too low a thermostat setting will allow the walls to cool to the point that condensation may occur on the inside walls themselves. For these reasons, thermostats should not be setback to temperatures of less than 55 degrees, with 55-60 degrees being the recommended range.

Low Cost - No Cost Energy Conservation Practices

There are a multitude of activities that the average homeowner can do to reduce energy consumption in the home that cost very little and do not require major changes in lifestyle or habits. The following is a "laundry list" of some of those ideas. Additional ideas or information on these suggestions can probably be obtained from local utilities or by contacting the Alaska Division of Energy and Power Development, 338 Denali Street, 8th Floor MacKay Building, Anchorage, Alaska 99501.

* Cook with a microwave oven. Uses as little as one-seventh as much energy as conventional oven.

* Install water flow restrictors in showers and faucets.

* Take showers instead of baths.

* Turn off the dishwasher after the rinse cycle and open the door so dishes can air dry.

* Use cold water or warm water wash.

* When using a conventional oven, heat more than one dish. Vegetables can be heated in the same oven that is cooking the meatloaf.

ENERGY CONSERVATION OPTIONS
for Alaskan Mobile Home Owners

- Use the right size pan for the burner. Too small a pan allows heat to go unused around the outside. Use lids.
- Keep freezer defrosted, allow no more than 1/4" of frost.
- Check door seals on refrigerators and freezers. Shut the door on thin piece of paper and pull. If it slips out easy there is a poor seal.
- Keep refrigerator and freezer coils clean.
- Replace oversized light bulbs with smaller wattage or flourescent fixtures.
- Keep furnace filters clean.
- Do only full loads in dishwashers, clothes washers and dryers.
- Be sure fireplace dampers close tightly -- do not burn the fireplace at colder temperatures.
- Use a timer on automobile engine heaters.
- Keep shades open on south facing windows during daylight hours.
- Allow food dishes to partially cool before putting them in refrigerator or freezer.
- Fill the sink -- do not allow continuous flow of water while shaving or doing dishes.
- Turn off unnecessary lights -- consider timer or photocell for outdoor lighting.
- Install timer on bathroom vent fans.
- Repair leaking faucets -- especially hot water faucets.
- Drain a couple buckets of water from the hot water tank a couple of times per year -- this avoids mineral build-up on the heating element.

ENERGY CONSERVATION OPTIONS
for Alaskan Mobile Home Owners

SUMMARY

Contrary to a somewhat popular belief the mobile home owner does not have to live with an energy inefficient dwelling. There are options available to him/her for retrofitting that are viable and cost effective. In some cases, retrofitting will allow for correcting other deficiencies in the construction of the unit and significantly extend its life. New products and systems are being brought on the market at an ever increasing rate as energy costs rise. It only remains for innovative energy auditors and homeowners to adapt new technology to existing structures.

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WOOD USE IN COMMERCIAL BUILDINGS

IS IT COST EFFECTIVE?

Robert W. Baxter
Manager
Energy Conservation
Incentive Program
Energy Branch
Government of Yukon

ABSTRACT

This paper considers the two basic types of measures available to a commercial operation which are designed to reduce energy costs. These are supply items (increasing the cost effectiveness of supplying energy) and demand items (reducing the need for heat within the building). A typical example of the latter is simply reinsulation, while an example of the former is increasing the heating plant efficiency in some manner. However, another supply measure available is fuel substitution.

In Yukon, the choices of substitution are minimal, basically limited to wood, as oil, electricity, and propane tend to be similar in price. However, when wood is used the convenience of automatic feed and easy storage disappear, which represents a real cost to the building operator.

These real costs are examined, not so much to determine their value accurately, but rather to get a feel for their cumulative magnitude. The "real" economics of wood are then compared to the alternatives. While anyone may dispute the values attached to the various tasks required to burn wood, the concept of evaluating more than only the obvious cost of the delivered energy when conservation or substitution is contemplated is sound.

The Yukon Territorial Government has been operating a program since January 1981 which provides free energy audits on commercial buildings, as well as funding a portion of the renovations. In the course of performing audits on a wide variety of buildings in the past three years, it has become apparent that there are two basic sorts of conservation measures which might be performed. The first of these are demand items.

Demand reduction items are those which cause the building to require less heat to condition it over the course of a year. A typical example of this is simple reinsulation. The reduced heat loss due to the reinsulation causes a reduction in fuel used throughout the heating season. Another typical example of this would be air sealing, through weatherstripping or caulking, which also affects building demand.

On the other end of the stick are supply items. These include measures which alter the supply of energy to the building, without affecting the actual total number of delivered joules the building will require. A good example of this would be the installation of a retention head burner. The saving which will result from this is not due to a diminished requirement for heat, but rather from the fact that the heat which is required is provided in a more efficient manner.

Of course, the implementation of both of these types of measures will "fight" with each other. To use the first example, let us assume that the attic space of a building has been reinsulated, reducing the need for heat from A to B litres of fuel oil per annum. Following this reinsulation, the furnace is retrofitted with a retention head burner, increasing its efficiency. For the sake of argument, let us assume a 10% saving will result from the burner retrofit. The actual saving is 10% of B, which is a smaller number than 10% of A, the pre-reinsulation saving which would have resulted. The burner retrofit will cost the same either way, and hence the payback which will result is lengthened since the building was reinsulated first.

This relationship holds true for all supply and demand related measures. It is true that two demand measures, such as a reinsulation and an air sealing, tend to be additive. An exception to this appears to be night setback, however. Setting the temperature back at night and on weekends does not significantly affect the heating plant efficiency, however does reduce the demand for heat. Unlike most demand items, however, it is not additive with other demand measures. It "fights" demand measures in a similar manner to supply measures.

The supply measures presented thus far are all efficiency oriented. There is, however, one other supply oriented measure which can be implemented, that being conversion. When one fuel is substituted for another, the demand for heat has not been altered, but the cost of providing this heat to the building has been reduced. The typical fuel which many individuals and businesses have converted to is wood, as most other conversions within Yukon do not significantly reduce the costs. At typical costs and efficiencies, wood is approximately 43% of the cost of oil per delivered joule. But is this the "real" cost of wood? Since it does not automatically feed from the storage to the heating plant, perhaps the cost is higher than at first appears.

Let us assume for the sake of analysis that we are dealing with a "showroom" type commercial enterprise, such as a car dealer or carpet showroom, which would consume ten cords of wood per annum for heating. Let us further assume for convenience that the wood is purchased at $65 per cord, which is the standard cost for wood in Whitehorse, cut to length and delivered. Also, the payroll burden per employee is set at ten dollars per hour.

The first item to be considered is stacking the wood into a pile. When wood is delivered, it will be dumped into a large stack, which is a waste of space, aesthetically unacceptable, and subjects the wood to the elements. It is estimated that it takes one hour per cord to stack the wood, or a total of ten hours. Table 1 summarizes the extension of this and all of the following into a total dollar value.

The wood of course must be split into kindling to start fires. A cord of wood consists of 128 cubic feet, and it is estimated that a typical stove firebox will hold four cubic feet of wood. Hence, a cord consists of 32 fires, or, it is assumed, 16 fire starts, as an average fire might be 2 stove loads. At ten to fifteen minutes each, it can be estimated that three hours will be required per cord to cut kindling. A similar estimate is used for the cost of hauling in and piling the wood indoors, three hours per cord. Also, the cost of loading wood into the stove when the fire is burning, and starting fires when required, is estimated at ten to fifteen minutes per load. In the interest of fairness, however, this was rounded down to 2½ hours per cord.

The only other time related item considered is based on a seasonal use, and that is the cleaning of the chimney and the ashes. This should be done every two weeks for a 34 week period, or 17 times. At an estimated half hour per cleaning, this amounts to 8½ hours per season.

Also to be considered is the cost of space occupied by the stove, indoor wood pile, and outdoor wood pile. The total amount of indoor floor space occupied by the stove, the small wood stack, and the clearance around the stove is estimated to be 40 square feet. At ten dollars per year per square foot for building rental, this amounts to a further $400 per annum. The outside space must also be considered, as the pile of wood occupies land which is also paid for, or worse, displaces a parking space which a customer might use, sending him off to a competitor. It is estimated that 300 square feet of space should be allotted to an outdoor wood storage area, at a cost of one dollar per square foot per year.

When these costs are extended, as per the table, it appears that the ten cords of wood actually cost $2,485, rather than the $650 that is at first apparent. This amounts to $248.50 per cord, or approximately $30 per delivered gigajoule, at typical moisture contents and efficiencies. Oil, on the other hand, has a value of about $20 per delivered gigajoule, or 2/3 the "real" cost of the wood heat. Is wood heat, therefore, really a better deal than oil for a commercial operator?

It is not totally fair to drop the issue at this point. There may indeed be credits to add to the account which has been tallied up. For instance, if we stick with the example of wood heating an auto showroom, it may in fact prove out that more cars can be sold with the wood stove. It is feasible that, given the "homey" atmosphere which can be created around the stove, customers will be more inclined to picture that car in their driveway. The impact of the stove "selling" one more car may be that the dealer profit can be subtracted from the $2,485 which the wood really costs. Is this a justifiable thing to do? Only the sales manager could answer this question, and it would only be a guess. But this guess may be the key which determines whether or not the wood heat option should be considered.

The conclusion of this exercise is that all factors must be considered for any retrofit measure. Many of these are obvious, many of these are difficult to attach dollar values to, but all of them must be considered, objectively and/or subjectively. Only in this way will be true costs be arrived at, and an intelligent decision be made.

Table 1 - Actual Wood Heating Costs

Item	Cost
1. Wood, cut and delivered, 10 cords @$65/cord	$650
2. Stacking of wood into outdoor pile, 10 hours @$10/hour	$100
3. Splitting of wood into kindling 30 hours @$10/hour	$300
4. Hauling in and stacking of wood, 30 hours @$10/hour	$300
5. Starting and reloading of fire, 25 hours @$10/hour	$250
6. Cleaning of chimney and ashes, 8½ hours @$10/hour	$ 85
7. Cost of inside floor space 40 ft² @$10/ft²	$400
8. Cost of exterior wood storage 300 ft²@$1/ft²	$300
	$2,485

Energy from the Forests of Canada

Robert C. Dobbs
Manager
ENFOR Program
Canadian Forestry Service
Ottawa, Ontario

Abstract

Canada is a forested nation populated by the world's foremost consumers of energy. Although the nation has enough energy to meet foreseeable needs, it does not have enough oil to sustain current consumption patterns. Because of this, a principal goal of current energy policy is to reduce oil consumption and make up necessary differences through the increased exploitation of other domestic energy sources.

Forest biomass now provides about 4 percent of the nation's energy budget, and it has the potential of providing a considerably greater portion. However, there are some formidable obstacles. In order to overcome these, new knowledge, methods, practices, machines and systems are required, and we must stimulate awareness of opportunities and demonstrate means of seizing them. to provide these requirements, the federal government launched in 1978 the energy from the Forest (or ENFOR) program.

ENFOR is a contract R and D program comprising biomass production and biomass conversion components. The production component is concerned with raw material supply, and thus with forest-oriented matters such as inventory, harvesting, environmental impacts and silviculture. The conversion component deals with the transformation of delivered biomass to energy, prepared fuels and energy-intensive chemicals. The production component is administered by the Canadian Forestry Service (CFS), and is the principal concern of this paper. The conversion component is administered by the renewable Energy Division of Energy, Mines and Resources Canada.

The ENFOR production program is administered through the 6 CFS Forest Research Centres and the Petawawa National Forestry Institute. It address four problem areas: Biomass Availability, Biomass Harvesting, Environmental Impacts, and Intensive Silviculture.

The program is now in the final year of its initial mandate. By the end of this year, some 150 projects will have been completed at a total cost approaching 15 million dollars. Major accomplishments will include the compilation of a National Biomass Inventory, the development of a computerized gaming tool for predicting the relative impacts of biomass harvesting and other stand management decisions, and the develoment of several prototype machines for harvesting and processing biomass.

ENERGY FROM THE FORESTS OF CANADA [1]

R.C. Dobbs [2]

Canadian Forestry Service, Ottawa

Every year Canadians each consume energy equivalent to nearly 9 tonnes, or 65 barrels of oil (Table 1). This per capita consumption is second highest in the world, exceeds that of our neighbors to the south, and is more than twice the amount consumed by other principal industrial nations. (Only the Grand Duchy of Luxembourg has a higher per capita energy consumption, and this tiny country devoted to mining and smelting could be readily dismissed as an anomaly, leaving Canadians the world's foremost users of energy.)

Factors contributing to Canada's high energy use are its substantial industrial development, its emphasis on primary manufacturing, the dispersion of its population over a large land area, its harsh northern climate and, until recently, the absence of significant economic or institutional constraints on energy development and use.

Canada's annual primary energy production is about 8,000 petajoules (PJ), or 190 x 10^6 tonnes oil equivalent (toe). Seventy percent comes from fossil fuels (petroleum, natural gas and coal); 23% is hydroelectricity and 7% comes from other sources (Figure 1). The 7% from "other sources" is about equally derived from nuclear electricity and forest biomass. The industrial sector consumes 35% of our secondary energy; 26% goes to the transportation sector, 18% for domestic and farm use, 13% for commercial use, and about 8% is consumed by the energy supply industries (Figure 2).

Canada has more than enough energy to meet its foreseeable needs, but we do not have enough oil to sustain current consumption patterns. In 1979, our demand for oil exceeded domestic production by 215,000 barrels/day (Figure 3). The problem is particularly acute in our eastern Maritime Provinces which are dependent on foreign oil to meet 83% of their total energy requirements (3). So long as this problem prevails, we are uncomfortably vulnerable to the whims of OPEC, to other extra-national upheavals and, ultimately, to the increasing scarcity of this precious "black gold".

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[1] Paper presented at the symposium "Towards Northern Energy Self-Sufficiency: Forest Biomass and Energy Conservation", 34th Alaska Science Conference; Whitehorse, Y.T., September 29 - October 1, 1983

[2] Manager, ENFOR (Energy from the Forest) Program

Solutions, of course, are to find more domestic oil and, increasingly, to use our other energy sources in place of oil. To provide a coherent approach to achieving these solutions, the Canadian Government established in 1980 the National Energy Program. This is, in reality, a series of programs under a broad framework intended "...to establish the basis for canadians to seize control of their own energy future through security of supply and utimate independence from the world oil market" (3). The centre-piece of the National Energy Program is a drive to reduce our demand for oil to the extent that, by 1990, our needs will be balanced by domestic production (Figure 3). A series of conservation and off-oil incentives are expected to reduce dramatically demand for oil in the residential, commercial and industrial sectors. Oil consumption is to be reduced 20% against a backdrop of an assumed average annual increase of 3.2% in economic growth. Oil's contribution to our energy budget will fall from 43% to 27% (Figure 4).

Other energy sources must, of course, make up the difference. The contribution from "renewables" (essentially forest biomass) is expected to double to 6% by 1990. If this target is met, the use of forest biomass for energy will actually increase by a factor of 2.4 since the 6% is a portion of a larger energy "pie", or "barrel".

Energy and the Forest Industry

Forestry is Canada's major industry. It directly employs over 300,000 people; one job in every 10 depends upon the forest industry (4). Canada produces 15% of the world's roundwood of softwood species, 16% of its wood pulp and 37% of its newsprint; 25% of exported manufactured forest products originate in Canada (5). Net exports of forest products in 1981 represented nearly $13 billion, more than the combined total accruing from the next four industrial sectors (5).

It should come as no surprise, then, that the forest industry is by far the largest energy consumer among Canada's industries. It uses about 685 PJ of energy each year, over one-third the total energy demand of the industrial sector (8). About 7.5% of the total consumption of oil and natural gas in Canada is accounted for by the forest industry. The pulp and paper segment of the industry is particularly energy intensive. It uses almost 4 times as much purchased energy per dollar of value added as the average for all Canadian manufacturing industries (1); energy costs represent 19.3% of value added by the pulp and paper industry, compared to a 5.8% average for all Canadian industry.

Table 1. Energy consumption (in tonnes oil equivalent per capita for selected countries

Luxembourg	10.77
Canada	8.70
United States	8.28
Sweden	5.90
Germany	4.25
United Kingdom	3.78
Japan	3.05

Source: IEA: 1978 Review of National Programs

This considerable dependence on purchased energy exists despite the fact that the forest industry generates over 40% of its own energy requirements (Table 2). The vast majority of this energy is produced and used in the pulp and paper segment, and comes from spent pulping liquors and wood wastes (1). In some instances, hog fuel is purchased from nearby sawmills.

Incentive for the industry to reduce purchased energy costs by using more forest biomass exists, or is likely to in the near future. Government programs aimed at stimulating this incentive are in place. Certainly the biomass itself exists in quantity.

Forest Biomass

About 47 $\times 10^6$ ODt (oven-dry tonnes)[3/] of forest biomass are brought from the forests to Canadian mills each year (7). About a third of this amount, some 15 $\times 10^6$ ODt, is residual to manufacturing processes and available for conversion to energy. Just over half of these solid residues are utilized for energy within the industry and provide over 150 PJ which, together with a similar contribution from spent kraft mill liquor, accounts for almost all of forest biomass' contribution to our primary energy supply. The remaining 7 $\times 10^6$ ODt of residues (the true "wastes") represent a potential 140 PJ of energy, and often a disposal problem for the industry. Half of these unutilized residues are generated in British Columbia.

Table 2 Forest Industry Energy Sources

	Pulp & Paper	Wood Industries	Logging	Totals
	-----------------petajoules-----------------			
Purchased fossil fuels and electricity	353	30	23	406
Black liquor	188	-	-	188
Hog Fuel	21	20		
	50 ←	-----------(50)	-	91
Totals	612	50	23	685

[3/] This figure, and similar data throughout the text, are derived from volume data by applying the factor 0,37 ODt m^{-3}.

About 70% of the above-ground biomass of a mature tree is contained in the merchantable bole (9); the remaining 30% is left near the stump or at landings in most logging operations. Also left in logged areas are trees deemed unmerchantable because of poor quality or small size, or because the species is unsuitable. Data in the literature indicate that the biomass available in non-merchantable trees and parts of trees (ex roots) remaining in logged areas ranges from one to over two times the amount in the merchantable boles (9). It seems reasonable to apply the median availability factor of 150% to harvest data to derive estimates of the woody biomass left on conventionally logged areas. Thus, each year we leave about 70 x10^6 ODt of biomass on the cutovers from which our annual harvest of 47 x10^6 ODt of merchantable boles is removed.

The allowable annual cut in Canada currently exceeds the annual harvest by around 25 x10^6 ODt [4/]. In applying the 150% biomass availability factor to this figure, we can estimate that an additional 37 x10^6 ODt of biomass theoretically could be tapped for energy purposes.

Finally, biomass energy plantations represent a medium- to long-term opportunity with immense potential. According to the Canada Land Inventory, 3.4% of Canada's total land area is abandoned farmland or unimproved land considered potentially arable; in area this amounts to about 31 million hectares (6). If one-quarter of this land were to support biomass energy plantations producing a modest 10 t/ha/yr, the total annual yield would approach 80 x10^6 ODt.

Taking these sources together, then, we see that nearly 200 x10^6 ODt of forest biomass could conceivably be grown and harvested for conversion to energy (Table 3). This amount would represent nearly 4000 PJ, or about one-third of the nation's projected primary energy demand for 1990.

Table 3: Unutilized sources of forest biomass for energy

	10^6ODt	PJ
Mill Residues	7	140
Logging Residues(including standing trees on logged areas)	70	1400
Unutilized Allowable Cut	37	740
Energy Plantations	80	1600
Totals	194	3880

[4/] Derived from volume data provided by G.M. Bonner, Forestry Statistics and Systems Branch, Canadian Forestry Service.

Such high theoretical potentials cannot be fulfilled, of course, due to numerous constraints. But they do give perspective, and even a sense of modesty, to the NEP goal of deriving 6.0% of our energy needs from forest biomass by 1990. In fact, achievement of the NEP goal for 1990 requires that we obtain an additional 420 PJ from forest biomass, or just over one-tenth of the theoretical potential shown in Table 3.

However, although our goal is to achieve a small fraction of the theoretical biomass energy potential, there are some formidable obstacles. Some of these are technological. In order to significantly increase the contribution of forest biomass to our national energy budget, we need new knowledge, methods, practices, machines and systems, and we must stimulate awareness of opportunities and demonstrate means to seizing them. To provide these requirements, the Federal Government launched the Energy from the Forest (or ENFOR) program.

The ENFOR Program

ENFOR is a contract research and development program aimed at securing the knowledge and developing the methods, machines and systems to facilitate a marked increase in the contribution of forest biomass to Canada's primary energy supply. The program was launched in the spring of 1978 and was authorized through fiscal year 1983/84. Funding over the 6-year period totals about $30 million.

Within ENFOR, there are two sub-programs -- or, perhaps more accurately, there are two ENFOR programs: Biomass Production and Biomass Conversion. The Production program is concerned with raw material supply, and thus with such forest-oriented matters as inventory, harvesting, environmental impacts and silviculture, while the Conversion program deals with the transformation of delivered biomass to energy, prepared fuels or energy-intensive chemicals.

Until this year both programs were administered by the Canadian Forestry Service (CFS), with the ENFOR Secretariat at CFS headquarters providing overall financial administration, coordination of report printing and distribution, and response to public enquiries. However, responsibility for the Biomass Conversion program has recently been transferred to the Renewable Energy Division of Energy, Mines and Resources; technical liaison services are provided under contract by FORINTEK Canada Corporation. For this year only, the ENFOR Secrataria tremains responsible for technology transfer for both programs.

Technology transfer is accomplished primarily through the distribution of contractors' reports and the publication of CFS Information Reports. Contractors also present the results of their studies through poster sessions at an annual Bioenergy R&D Seminar, which is to be held in Ottawa on March 26-28, 1984. The availability and content of reports is made known through the periodic publication of ENFOR Review. This periodical contains abstracts of available reports and information on how they may be obtained. It also contains a complete list of ENFOR projects to date.

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We take steps to make the program known to the general public as well. We have developed a 16 mm audio-visual presentation, and a large information exhibit that has been displayed at a number of energy shows and symposia such as the Bio-Energy World Congress in Atlanta, and at events such as the Canadian National Exhibition in Toronto. We have also published a program brochure and a periodic newsletter highlighting interesting developments.

The Biomass Conversion Program

The Biomass Conversion program is concerned with process technology for the conversion of forest biomass into energy, prepared fuels or industrial chemicals that will significantly reduce traditional fossil fuel consumption. Problem areas are:

Preparation of Feedstocks for Conversion Systems
Direct Combustion Technology
Prepared Fuels Conversion Technology
Industrial Chemicals Conversion Technology

Projects under the Preparation of Feedstocks problem area are concerned with materials handling, size modification, moisture content reduction and storage. Most direct combusion projects deal with large-scale hog fuel boilers. Prepared Fuels projects are directed towards the conversion of biomass to gaseous, liquid or solid fuels with enhanced energy density, cleanliness, or improved transport and storage properties. The emphasis in the Conversion program clearly has been on prepared fuels, and particularly on gasification. A considerable amount of work has also been done on Direct Combustion.

The Biomass Production Program

The Biomass Production Program is administered through the 6 regional CFS Forest Research Centres and the Petawawa National Forestry Institute. Scientists at these participating establishments initiate project proposals in response to regional and national program priorities; they implement and manage approved projects; they carry out in-house R&D related to our contract research; and they prepare reports and implement technology transfer. This involvement by regional personnel ensures the regional perspective necessary to the success of a land- or resource-based national program.

The Production Program addresses four problem areas: Biomass Availability, Biomass Harvesting, Environmental Impacts, and Intensive Silviculture.

The program objective associated with the Biomass Availability problem area is "...to determine the amount of biomass in Canadian forests, and to estimate its potential contribution to the nation's energy requirements."

Biomass availability is the major premise underlying the ENFOR program, as well as being the subject of many of its projects. For, while rule-of-thumb estimates and a few preliminary studies may suffice to initiate such programs, reliable data

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on the quantity, form and location of forest biomass are needed to enable federal and provincial policy-makers to make decisions on forestry and energy policy, and on the need for, and optimum location of, biomass conversion plants. No adequate compilation of forest biomass data yet exists for Canada, or for any province or territory.

Many ENFOR projects have been directed to this requirement, however. The general approach is to collect field data relating oven-dry biomass to tree size parameters. From these data, regression equations are constructed for application to provincial forest inventory data. The resulting biomass data will be summarized by land units (generally cells 10 by 10 kilometers in size) for all inventoried forest land in Canada by mid-1984. A data management system for collecting, storing and retrieving biomass data has been developed and the necessary biomass regression equations are now available. Also completed, but not yet published, is a compilation of biomass data (following the procedure outlined above) for the Province of Newfoundland This serves as a pilot project for similar compilations for the other provinces and territories.

Other Biomass Availability projects are concerned with methodologies for direct inventory, the amount of biomass left on sites following conventional timber or pulpwood harvests, and forest growth rates in terms of biomass.

The program objective associated with the Biomass Harvesting problem area is "...to develop and test methods and systems of harvesting, processing and delivering forest biomass for conversion to energy or fuels."

Specialized equipment and systems are required to effectively harvest and process logging residue, sub-merchantable trees and brush, and non-commercial stands. Few systems have been developed for these purposes either in Canada or elsewhere.

ENFOR projects concerned with this problem area involve second-pass and integrated harvesting trials using conventional equipment, and the development of specialized new machines for biomass harvesting and processing. Under an ENFOR contract, the Forest Engineering Research Institute of Canada (FERIC) has developed the Recufor, a prototype machine for collecting logging slash, reducing it to conveyable-sized pieces and delivering it to roadside.

Under other ENFOR contracts, FERIC has also developed a prototype roll crushing machine for breaking down biomass and squeezing out free water, and is currently fabricating a logging residue processor for handling tops and limbs that accumulate at roadside and landings in full-tree harvesting operations.

Another harvesting machine under development, although not by FERIC, is the Crab Combine which is the licensed Canadian successor of a Finnish machine call the Pallari swath harvester. This machine will harvest and chip brush or trees up to 15 cm in diameter moving along a 2 to 3-metre-wide swath. The Crab Combine will be fabricated this winter and field tested next summer.

The general objective for projects in the Environmental Impact problem area is "...to assess the environmental impacts of intensified biomass production and harvesting for energy purposes."

The prospect of exploiting forest biomass for energy gives rise to serious concern that the forest environment will be affected adversely. Compared to conventional shortwood and tree length harvests, full tree or biomass harvests entail much more complete removal of organic matter and nutrients, and biomass harvests may be much more frequent. Possible effects on soil stability, seedling microclimate and wildlife habitat must be studied.

ENFOR projects are addressing all of these concerns. The emphasis, however, is on potential losses of site productivity, and on means by which such losses might be ameliorated. One of the most important ENFOR projects under this problem area is the development, by Dr. Hamish Kimmins of the UBC Faculty of Forestry, of a computer simulation model that will enable foresters to predict the effects of whole tree harvesting, short rotations and various cultural treatments on forest site productivity. This model, termed FORCYTE for FORest CYcling Trend Evaluator, is exciting a great deal of interest in the scientific community worldwide. The model has been calibrated for forest types in B.C., and it is being calibrated in Ontario and Newfoundland under current ENFOR contracts.

The fourth problem area in the production program is Intensve Silviculture. The overall objective is "...to develop and test methods and systems for increasing biomass production."

We speak of forest biomass as being a renewable energy source. But whether this promise of renewability will be fulfilled or not depends on the degree to which we develop and apply silvicultural practices. Unfortunately intensive silviculture is not widely practiced in Canada and, while general principles are well-established, site-specific knowledge is often lacking. Silviculture of agricultural intensity must be practiced to establish and tend the kind of high-yielding energy plantations on which major biomass energy contributions will depend. There is need for considerable honing of our knowledge of site preparation techniques, plantation establishment and pest control methods, and the development of machinery and implements to facilitate these operations.

In spite of the need for work in this problem area, the ENFOR level of effort is relatively low. This is due partly to the limitations of contract research, and partly to the perception that energy plantations represent a longer-term opportunity to derive energy from our forests than utilizing logging residues and non-commercial trees and stands.

The most important ENFOR project in this problem area is examining the potential use of soil nitrifying species and mycorrhizal symbioses as means of rejuvenating soils overtaxed by intensive biomass production. This project is being carried out by Dr. André Fortin and his group at Laval University.

Through other projects we are providing peripheral support to the Ontario Ministry of Natural Resource's fast-growing hardwoods program. We are also studying the special problems of regenerating full-tree harvested areas.

The ENFOR program comes to the end of its original mandate next March. At that time, approximately $13.4 million will have been spent directly on Biomass Production projects (Table 4). Projects in the Biomass Availability problem area, most contributing directly to the National Biomass Inventory, will have received $5.4 million or 40% of the funds. Biomass Harvesting projects will have received $4.4 million or 33% of the funds. Next come Environmental Impact projects with $2.0 million (15% of funds) and Intensive Silviculture projects with $1.1 million (8%); the remaining $0.5 million (4%) was spent on projects that do not clearly fall within any of these problem areas.

Table 4 Approximate distribution of ENFOR Biomass Production funds among problem areas (through 1983/84).

Problem Area	Project Costs ($'000 000)	Percent of Total Project Costs
Biomass Availability	5.4	40
Biomass Harvesting	4.4	33
Environmental Impacts	2.0	15
Intensive Silviculture	1.1	8
Miscellaneous	0.5	4
Totals	13.4	100

Next Year and Beyond

Although we are now in the final year of ENFOR's original mandate, the forest energy R&D that has been carried out under the Biomass Production program will continue next year, and probably for several years beyond. What is not yet clear is whether the work will continue under the name ENFOR. Funding will taper off somewhat (about $2.8 million next year compared to this year's $3.5 million).

Work in the Biomass Availability problem area will be largely completed next year with the publication of the Forest Biomass Inventory of Canada. Biomass Harvesting work will continue, probably at a slightly reduced funding level, while funding of Environment Impacts projects will proportionally increase.

The ENFOR program has considerably advanced the technology of energy forestry, and it has increased awareness that energy is a forest product. Any serious effort to further develop forest biomass as a renewable energy source must be backed by a strong and flexible on-going R&D program. If the prospect of deriving significantly increased amounts of energy from the forest has important implications for energy planners, then it has downright profound implications for forest managers. Where energy biomass is to be taken from the forest, every aspect of management from regeneration, through inventory and harvesting, to milling and marketing can be affected. At all stages it will be necessary to develop effective management techniques and systems if raw material supply is to be assured.

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Figure 1 SOURCES OF PRIMARY ENERGY

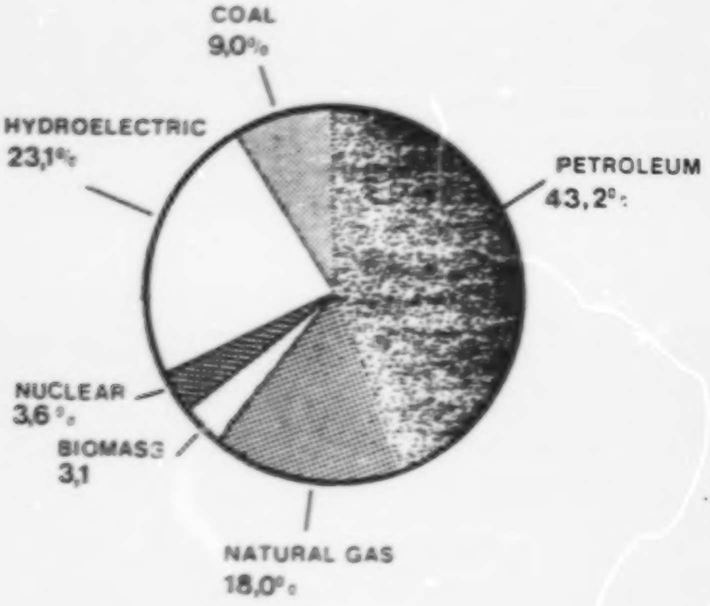
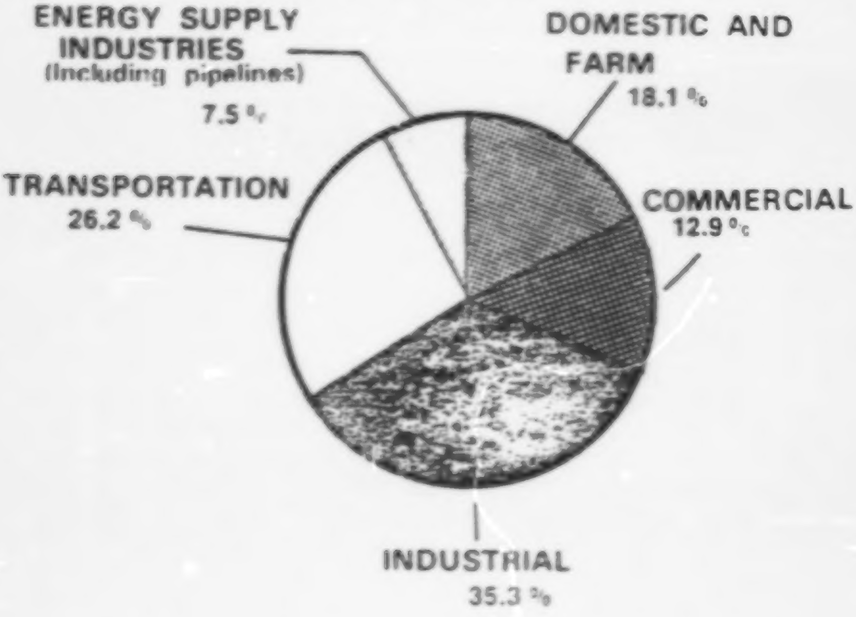
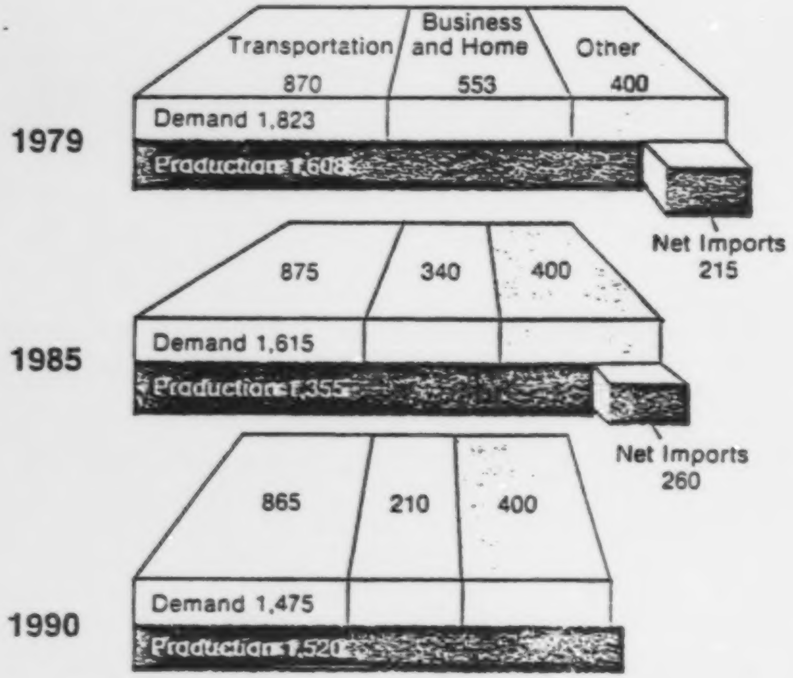


Figure 2 CONSUMPTION OF SECONDARY ENERGY



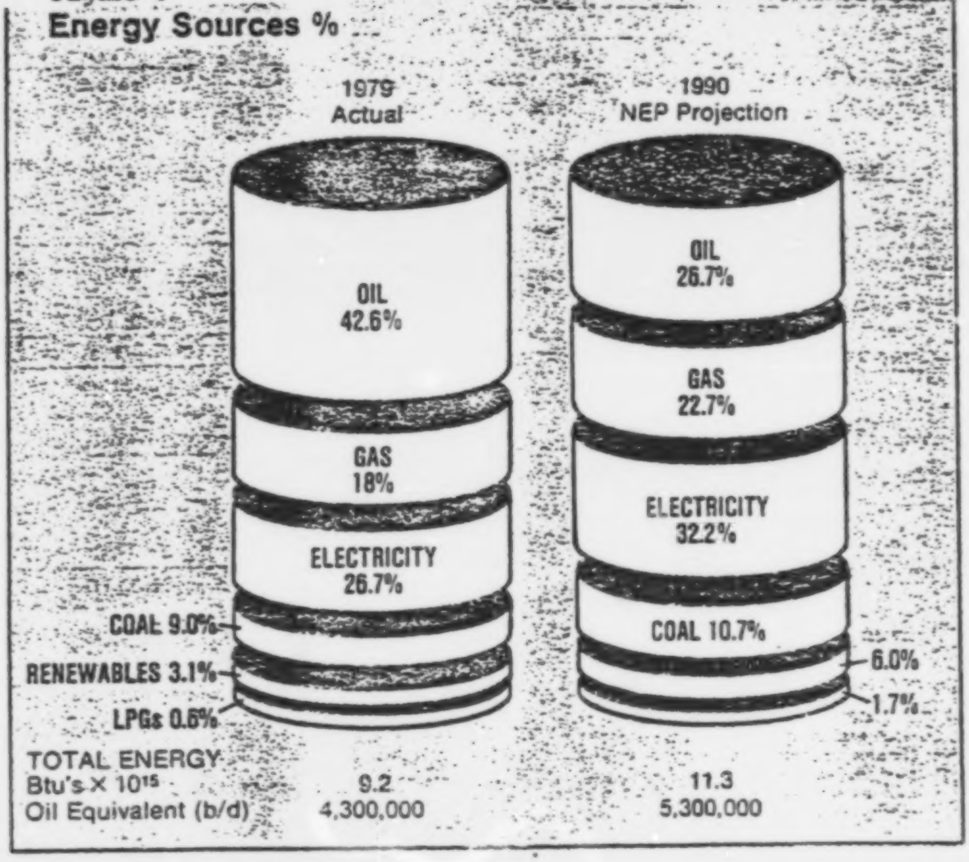
SOURCE: ENERGY UPDATE 1980. E.M.R.

Figure 3 **Canadian Oil Supply and Demand (Mb/d)**



Source: The National Energy Program 1980.
Energy, Mines and Resources Canada

Figure 4



Source: The National Energy Program 1980.
Energy, Mines and Resources Canada

Management of Forests in Interior Alaska

John C. Zasada
Institute of Northern Forestry
U.S. Forest Service
Fairbanks, Alaska

Abstract

Forest management activities are conducted at different levels of intensity. Four intensity levels are:

1) harvest with no concern for regeneration
2) harvest and assure natural regeneration
3) harvest and regenerate artificially
4) harvest, assure regeneration and tend stands following regeneration establishment.

The majority of forest harvesting in the interior of Alaska has been done with little regard for future forest development or yield. The most intense period of harvesting occurred during the gold rush and subsequent community development. In Alaska, there was little formal concern about forest regeneration and sustained yield until the mid to late 1960's. At about that time, management on lands managed by the State of Alaska increased to level 2. This increased interest culminated in 1978 with the passage of the Alaska Forest Practices Act. The creation of a division of forestry within two state forests further emphasized an increased commitment to improved forest management practices. On private land both level 1 and 2 management are practiced.

The higher levels of management (3 and 4) have occurred on an operational scale in interior Alaska. However, this is the exception rather than the rule. Research is underway to determine the effect of practices such as fertilization and stand density control on forest productivity. This paper discusses the silvicultural practices used at these various levels of management as well as the results of research concerning regeneration and growth potential.

MANAGEMENT OF FORESTS IN INTERIOR ALASKA

by
John C. Zasada
Institute of Northern Forestry
U.S. Forest Service
Fairbanks, Alaska 99701

INTRODUCTION

Interior Alaska is known for it's scenic beauty, wildlife populations and wilderness. The forests of this region are a vital component of this panorama and are an integral part of Alaska's scenic beauty. In addition to providing this background in which other values are of equal or greater importance, these forests provide a source of valuable traditional and unique forest products which appear to be of increasing importance to many Alaskans. Forests cover about 106 million acres or 32 percent of Alaska. Of this area, about 23 million acres are classified as commercial forest land capable of producing 1.4 m^2/ha/yr (20 ft^3/a/yr) (Hutchison 1967). White spruce, paper birch, aspen and balsam poplar occur on the productive sites while black spruce and tamarack predominate on the less productive forested sites. Information on forest productivity and distribution can be found in Zasada et al (1977) and Van Cleve and Viereck (1982).

In spite of the fact that forests cover large areas in interior Alaska, they are often overlooked as a significant natural resource. This viewpoint is the result of the northern location of these forests and all this means in terms of low annual temperature, frozen soils and short growing seasons. That these forests are, in general, not as productive as their more southern counterparts cannot be argued. However, this does not mean that there is not a demand for local forest products. Because of this demand there is a need to conduct some level of management or to know the result of a no management strategy to the availability of forest products in the future.

The purpose of this paper is to describe the present management situation in interior Alaska, particularly the Tanana Valley, as well as to consider past practices and what might occur in the future. Because the level or intensity of forest management is determined by factors other than biological considerations (e.g. forest utilization, economics and government regulations) brief consideration will be given to these variables as they relate to interior Alaska. It must be stressed that the review of these latter topics is brief and seen from the viewpoint of a silviculturist and not a specialist in each area.

FOREST USE

The forests of interior Alaska have been used by Alaska Natives for centuries. Nelson (1977) discussed the direct use of trees and other forest vegetation by Alaska Natives. He observed that white spruce was the most widely used species and paper birch was second in importance. Black spruce was apparently used to a lesser degree than the other species.

The most intense period of forest exploitation occurred during the gold rush and settlement period of the early 1900's. This period of heavy utilization ended as air and surface transportation became more efficient. I am not aware of any reliable estimates of the quantity of wood used during this period. However, one cannot escape the conclusion that vast quantities of wood were used for many purposes when viewing old photographs and reading accounts of activities during these early days.

The pattern and level of utilization was mixed during the 1950's and 60's. Use was relatively low except in isolated areas near towns and villages. During this period there was an increased dependence on lumber manufactured outside of Alaska and on fossil fuels for heating and energy production. From the late 1960's to the present, utilization and demand have increased significantly. The most dramatic increase has probably been in the demand for fuelwood (Table 1). During this 10 year period, the number of firewood permits issued increased by a factor of about 200 and the estimated harvest of fuelwood increased about 60 fold. Annual cut of white spruce for lumber and houselogs has increased relatively little when compared with firewood utilization during this same 10 year period.

Table 1. Estimated fuelwood consumption 1) in the Fairbanks area 1973-82.

Year	Estimated total cords harvested 2)	No. of personal use woodcutting permits issued
1973	504	112
1974	1,201	267
1975	986	219
1976	1,314	292
1977	1,962	436
1978	3,829	851
1979	12,000	2,009
1980	26,000	2,100
1981	35,000	2,714
1982	29,000	2,197

1) Taken in part from Gasbarro and Fox (1980) and from information made available by the Alaska Division of Forestry.

2) Figures presented for the later years probably over-estimate the quantity of wood actually harvested. The reason for this is that most personal use permits allow the harvest of 10 cords and most personal use woodcutters take less than what is allowed.

These changes in the amount of wood utilized have been accompanied by demand for wood from a wider variety of species. White spruce is most important for building materials while paper birch is used relatively little for this purpose but is the most sought after species for firewood.

In addition to these more common uses there are a variety of less common forest products that are used on a small scale. For example birch sap is collected in the spring by some individuals for the purpose of making syrup. This is a common practice in some parts of Russia but has little impact in Alaska (Ganns et al 1982). Other forest products used on a personal level include cottonwood and balsam poplar bark for carving and birch bark for basket making.

LAND OWNERSHIP AND MANAGEMENT REGULATIONS

The ownership or management responsibility for the land is an important factor in determining the level and type of management. Prior to statehood all of the land was essentially under the jurisdiction of the United States government. Small amounts of land had been turned over to individuals under homesteading and mining laws and as native allotments prior to statehood.

The Alaska Statehood Act of 1958 allowed the state to select 103.5 million acres. In 1971, another major piece of legislation, the Alaska Native Claims Settlement Act, permitted Alaskan Natives to acquire title to approximately 40 million acres. Lands selected by the State of Alaska and the regional and village Native corporations have had high resource values and as a result much of the productive forest land is or will be managed by the State and Alaska Native corporations.

State lands have only recently been classified specifically for forest management. The most significant classification is a 1.6 million acre area in the Tanana Valley. This area, named the Tanana Valley State Forest, was established by the state legislature in 1983 and will be managed under the principles of multiple use and sustained yield. Management plans must be prepared for this state forest by 1986.

The Alaska state constitution mandates that renewable resources shall be managed under the sustained yield principle. The Alaska Forest Resources and Practices Act, enacted in 1979, further defines forest management practices on state and certain private lands. The first set of regulations required by this law became effective in 1981. Although still relatively general in nature these regulations do establish requirements for slash treatment, reforestation and insect and disease prevention.

FOREST MANAGEMENT

Forest management in interior Alaska is in it's infancy. In terms of expenditures, the dominant activity is fire management. This activity will not be considered in this discussion. Management practices which relate specifically to wood production can be categorized as those used in stand regeneration and those used to guide forest development in established stands. At present, regeneration activities are relatively more important than post-establishment management practices. The following discussion will concentrate on regeneration considerations.

Regeneration practices can be placed in 3 general categories (Braathe 1980):

1. Harvest merchantable trees and stands with no regard for future forest development. This is the lowest level of management.
2. Harvest merchantable trees and treat site in such a way that natural regeneration is encouraged. This is often described as a medium level of management intensity. However, any prescription for natural regeneration may include a combination of silvicultural systems and site treatments.
3. Artificial regeneration by planting or sowing of the most important species soon after harvesting. This is a high level of management and is designed to regenerate the harvested area as quickly as possible.

The lowest level of management was practiced exclusively until the mid to late 1960's. Stands were harvested and the sites left to develop naturally. Regeneration on these sites was variable and determined by such things as preharvesting stand composition, post harvest seed supply, amount of organic matter disturbance during logging and the development of herbaceous and non-tree plant competition.

Although regeneration of all species is limited under this type of management, aspen, birch and balsam poplar are less affected than white spruce. The reason for this is that hardwoods reproduce vegetatively as well as by seed. Thus if these hardwoods are present prior to harvest they will be present to some degree after logging due to vegetative regrowth from stump sprouts, root suckers or buried branches. White spruce regenerates only from seed on these sites and thus suitable seedbed conditions must be present.

Under this management regime, Fox et al (1980) observed that white spruce regeneration averaged 24% (range 6-50) milacre stocking. Birch stocking averaged 32% milacre stocking (range 4 to 50%). Stocking percent for both species and aspen combined averaged 46 percent. Using 40% as an acceptable stocking level (Fox 1980), these observations indicated that 11% of the areas had adequate white spruce regeneration and 33% adequate birch regeneration. When all tree species were combined 66% of the areas were adequately stocked. Fox (1980) concluded from this that in order to determine the acceptability of regeneration under this low level of management, land managers had to determine what species or combination of species was most acceptable.

Because of the generally poor regeneration of white spruce, there have been increased efforts to encourage natural regeneration of this species on lands managed by the state in particular. The main practices have been to limit clearcut size so that a seed source is present within 300-400 feet of the cutover. In addition seed bed preparation has become a common practice.

The effectiveness of these practices on an operational basis has not been fully analyzed. Results of research indicate that these methods can result in 100% white spruce stocking on exposed mineral soil on upland sites (Zasada and Grigal 1978). These practices also provide for more prolific hardwood regeneration; percent stocking and seedling density will depend on seed supply. Silvicultural systems other than clearcutting have been tried on an experimental basis only. The shelterwood system resulted in stocking and seedling densities similar to those in small clearcuts two years after harvesting and site preparation (Zasada and Grigal 1978). An exploratory study indicated that a group selection system provides good conditions for regeneration establishment (Zasada et al 1978). There has, however, been little consideration given to uneven aged management.

Although encouraging natural regeneration is usually considered to be a low to medium level of management intensity this does not mean that the options and combinations of options available to obtain regeneration are simple. A mix of harvesting methods, silvicultural systems, various types of mechanical site preparation and prescribed burning create an array of choices depending on site conditions and desired species. Up to this time the use of these various options has been limited.

The establishment of a nursery for the production of containerized seedlings in 1975 made the third regeneration option available to land managers in interior Alaska. This nursery, first established at the Palmer Plant Materials Center, was moved to Eagle River, Alaska in 1983. It is operated by the Alaska Division of Forestry and can produce about 600,000 seedlings per year.

Planting has been the only type of artificial regeneration used to date. It has been used mainly to restock older cutovers which had regenerated poorly. As of 1982, about 400 acres had been planted (Clautice, personal communication [1]). Unfortunately much of the planted area was destroyed by the Rosie Creek fire in 1983.

There has been little research on artificial regeneration in interior Alaska. Gardner (1983) has shown that planting and artificial seedling both benefit from site preparation on floodplain sites in Yukon. Scandinavian research has shown repeatedly that organic layer manipulation is essential for rapid establishment and early growth of planted seedlings (Gasbarro 1982).

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[1] S.F. Clautice, Alaska Department of Natural Resources, Division of Forestry, Fairbanks, Alaska 99701.

Although there has been less attention given to thinning in established stands, these cultural practices are being used. The Alaska Division of Forestry has an operational program designed to thin white spruce and mixed white spruce-hardwood stands. The harvested material is sold to the public for firewood. This program has been carried out in cooperation with the University of Alaska's Intensive Forest Management program. Research suggests that significant increases in growth of individual white spruce can occur as a result of thinning (Van Cleve and Zasada 1976).

MANAGEMENT IN THE FUTURE

It is difficult to guess what the future holds for forest development in interior Alaska. The rate of forest development will be determined by economic considerations. The greatest impact on the forest resource would result from the establishment of a pulp mill or fiber/particle board plant. The raw material to support such a plant exists and plants based on similar forest conditions exist in Canada and Scandinavia.

With regard to regeneration practices, the Alaska Forest Resources and Practices Act sets standards for regeneration on lands managed by the state and certain private lands. The regulations under this act provide for a 10-year regeneration period. Seedling density and stocking levels are not well-defined at this time but the regulations state that seedlings must be evenly distributed and that a density of 500 seedlings per acre is recommended. The relative importance of natural and artificial regeneration is not known at this time. However it seems likely that natural regeneration will be the least expensive option and it will provide well-stocked stands under the right conditions. On lands not covered by the forest practices act the lowest level of management will probably continue to be practiced.

One positive step in improving forest practices was the establishment of a reforestation fund. Monies for this fund are derived from receipts for timber sold from state land. The funds provide a source of money that is available for forest management activities on state lands and should make planning and implementation of forest management practices more efficient and timely.

In conclusion it must be stated that this paper has been very brief and it's scope confined to timber management considerations. There is at least as much interest in managing lands for wildlife habitat and recreation. In fact, on lands established as state forests, multiple use management is required by law. In order to meet these multiple use objectives, a wide range of silvicultural practices must be understood and available so that the variety of forest conditions can be created to meet this range of needs.

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Resource Policy Impacts on Forest Management: Fire Management and Land Disposal in the Tanana River Basin, Alaska

Martha L. Welbourne
Division of Research & Development
Department of Natural Resources
Anchorage, Alaska

Abstract

The use of ecosystem processes to predict long term ecosystem changes, and the use of basic ecological units as the foundation for impact evaluation, are fundamental to ecologically based policy analysis. A case study is presented here in which the impacts on forest resources of state policies for fire management and land disposals are assessed over 21 million acres in the Tanana River Basin. Forest succession patterns are used to predict long term changes in a dynamic forest ecosystem. Changes in abundance of vegetation are interpreted for their impact on net forest productivity, availability of wood products, the amount of land available for sustained yield management, and the ability of the State of Alaska to meet its objectives for these parameters.

Fire management policy through 1982 resulted in active suppression of nearly all wildfires in the Tanana Basin. Suppression significantly lengthened fire cycles in the study area. Over time these cycle changes would result in a loss of successional non-forest vegetation and young forest types, coupled with expansion of older, spruce dominated forests. Fuel wood volume, net productivity, and manageable land area would be reduced in the long term while sawtimber and houselog volumes might increase.

Land disposals in the Tanana Basin convert forests to developed areas and commit the State to a continued policy of active fire suppression even in remote areas. Amplification of the fire suppression effects on forest resources is thus a secondary impact of the land disposal policy. In addition, residential and recreational development of forested areas would diminish the forest land base net productivity, and the potential for harvesting all types of wood products. Together, the land disposal and fire suppression policies decrease the likelihood that the State can meet its objectives for wood products.

Resource Policy Impacts on Forest Management: Fire Management and Land Disposal in the Tanana River Basin, Alaska

Martha L. Welbourn, Ph.D.

Forest management practices and the harvest of wood products are determined by governmental resource policies as well as by biological potential and physical constraints. Forestry actions often are affected by decisions that include not only timber management policies, but also policies not intended primarily to direct wood production programs. These policies affect forest ecosystems in complex ways that can make it difficult to achieve established forestry goals.

This study presents two examples of the effects of public policies on forest management in interior Alaska. The policies analyzed are those of the State of Alaska with respect to fire management and land disposals. Policy effects are assessed by using forest succession patterns to predict long term changes in the relative abundance of forest vegetation types.

Study area

The effects of these policies were examined across the Tanana River Basin in interior Alaska, an 8.5 million ha area containing approximately three million ha of forested land (Figure 1). Most of the lands in the Tanana Basin are publicly owned, and over three quarters of the land area is owned by the state or selected as part of its remaining entitlement. Open and closed forests of birch (_Betula_ _papyrifera_ _humilis_ [Marsh], aspen (_Populus_ _tremuloides_ [Michx.], and white spruce (_Picea_ _glauca_ [Moench] Voss) occur on the relatively warm, well-drained slopes of the Yukon-Tanana uplands and the floodplains of rivers and streams. Cottonwood (_Populus_ _balsamifera_ _balsamifera_ [L.]) is also an important component of floodplain forests. Black spruce (_Picea_ _mariana_ [Mill.] Britt., Sterns, and

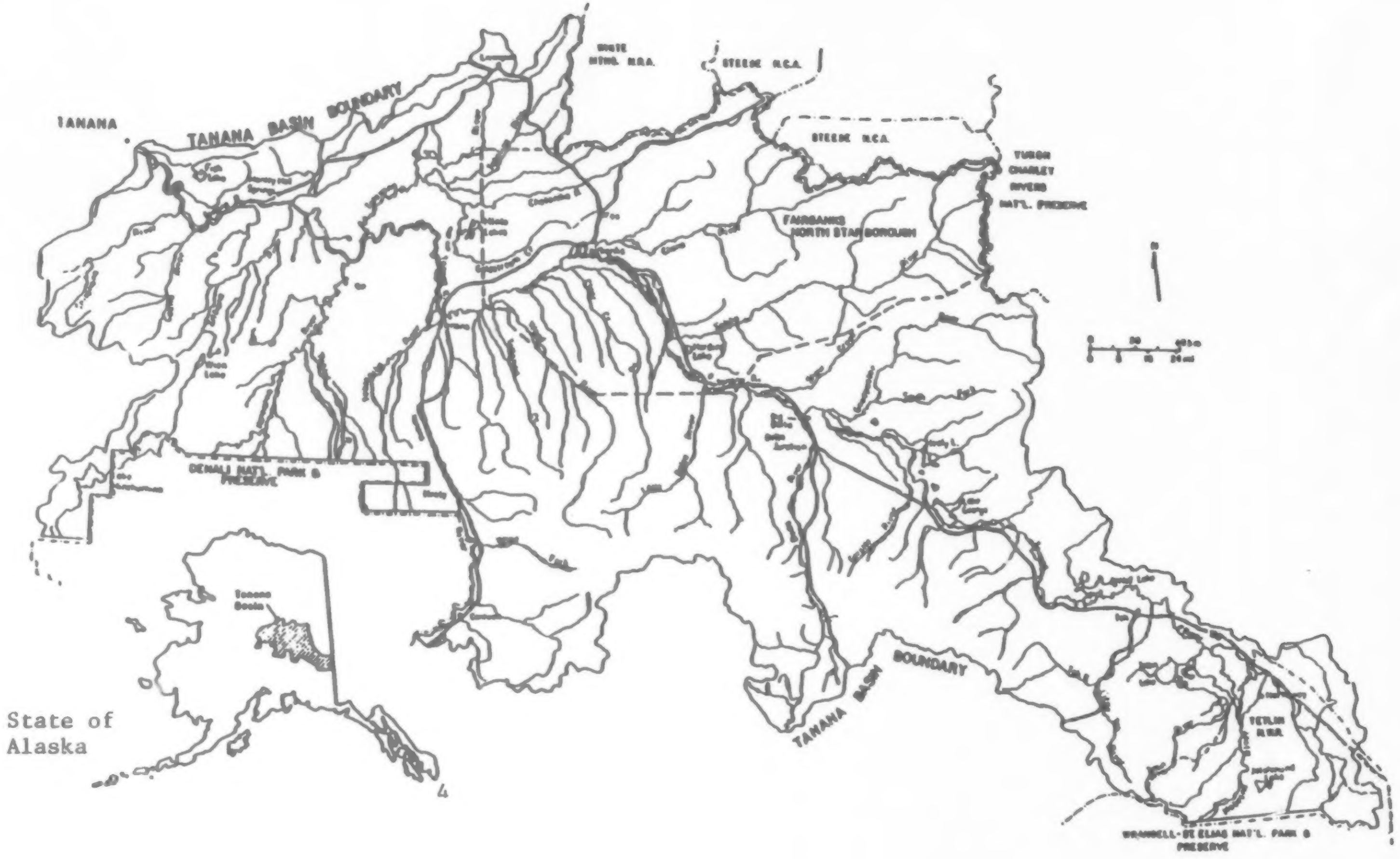
TANANA
TANANA BASIN BOUNDARY
WHITE MTNS. N.R.A.
STEESE N.C.A.
STEESE N.C.A.
YUKON CHARLEY RIVERS NAT'L. PRESERVE
FAIRBANKS NORTH STAR BOROUGH
DENALI NAT'L PARK & PRESERVE
TANANA BASIN BOUNDARY
TETLIN N.W.R.
WRANGELL-ST ELIAS NAT'L PARK & PRESERVE
Tanana Basin
State of Alaska

Figure 1 Location and boundaries of Tanana Basin study area.

Pogg.) forests and woodlands cover many cold, poorly drained sites on flatter areas and north facing slopes.

Wildfire always has been common in Tanana Basin forests. It is estimated that prior to 1940 an average of approximately 49,000 to 83,000 ha burned annually.[1] From 1940 to 1981, an average of 31,000 ha burned each year. During this period 265 fires from 40 to 200,000 ha in size were recorded. About half of these were due to lightning, and the remainder to human causes.

Fire management policy

Beginning in 1940, the policy of both the federal and then-territorial governments was to suppress all wildfires in interior Alaska. In the early years of this policy, implementation was difficult due to limited access and poor detection systems. In the Tanana Basin, fewer than 60% of the fires greater than 40 ha in size that were detected received active suppression in the decade from 1940-1949 (Figure 2). Improvements in technology and transportation rapidly increased the ability of the fire fighters to detect and reach fires in remote areas. By the period from 1970 to 1981, suppression efforts were carried out on over 95% of all known fires in size classes greater than 40 ha. The average area burned annually decreased from approximately 65,000 ha in the period prior to active suppression, to less than 25,000 ha in the period from 1970-1981. Conversely, the mean fire cycle, or the length of time required to burn an area equal to the total area under study, increased from 107 years to 288 years in the Tanana Basin. This means that, on the average, a given area burned much less frequently than in earlier times. This change occured despite trends toward more severe weather conditions for fire occurence over the same period (Welbourn, 1983).

[1] These figures are derived from estimates for the whole of interior Alaska reported by Barney (1971).

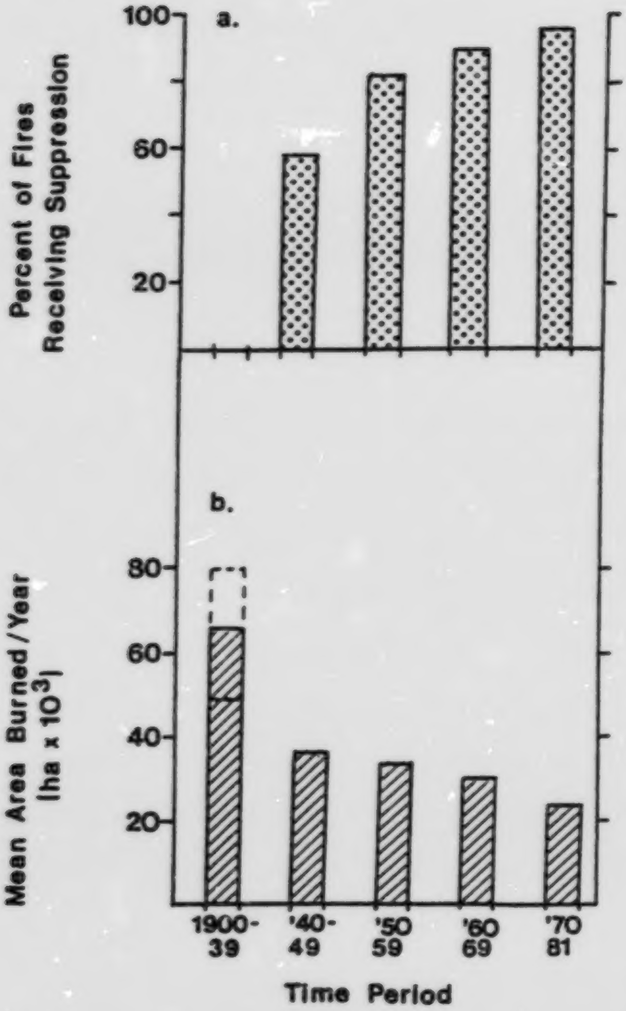

Figure 2 Active suppression, 1940-81: (a) percentage of all fires in the Tanana Basin study area greater than or equal to 40 ha (100 ac) receiving active suppression, and (b) mean annual area burned in the Tanana Basin study area, 1940-81. Dashed lines for the period 1930-39 indicate the range of estimates for average area burned annually prior to 1940. Averages for 1900-39 adapted from Barney (1971); for 1940-81 from BLM and ADNR individual fire reports.

Reductions in the area subject to wildfire affect wood production by changing the distribution of vegetation types Fire is the most widespread type of disturbance in the boreal forests of interior Alaska (Zasada et al., 1977) and is the major factor in starting new successional cycles in forest stands. In the absence of other disturbance, suppression of wildfires decreases the amount of land in early successional stages and increases the average age of forest stands.

For example, the following post-fire successional sequence is typical of many relatively warm, well-drained sites in interior Alaska.[2] For approximately 15 years after burning, nonforest vegetation -- mosses, herbs, grasses, and later shrubs -- is dominant. Following this period, hardwood cover predominates for approximately 80-90 years, by which time white spruce has entered the canopy, resulting in a mixed forest. The mixed forest lasts until hardwoods grow decadent and drop out of the canopy, leaving a white spruce forest about 150 years post-fire. If the site is not disturbed, white spruce cover may persist indefinitely, or, as suggested by Viereck (1970), Strang and Johnson (1981) and Black and Bliss (1980), black spruce may invade the site. Long disturbance-free periods allow development of a thick organic mat under the white spruce cover, insulating the forest soil and reducing soil temperatures. The colder and wetter soils, and the lack of a mineral soil seedbed then favor replacement of white spruce by black spruce.

This successional sequence is summarized in Figure 3a. The lower part of the diagram (Figure 3b) shows the mixture of forest types associated with fire cycles of different lengths given this successional pattern. The diagram can be

[2] The sequence presented here is based on successional patterns described by Foote (in press).

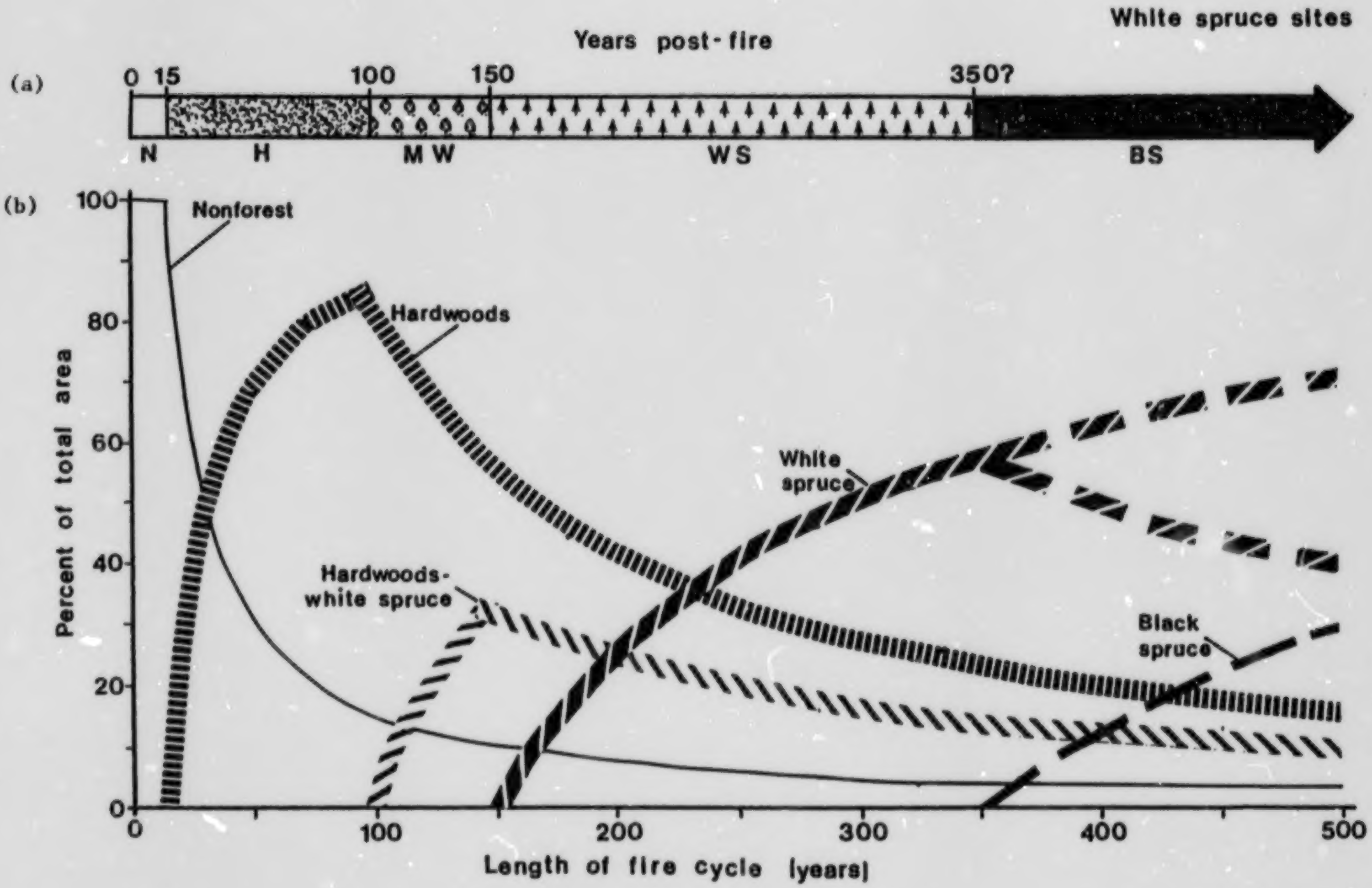

Figure 3 (a) Post-fire succession pattern of white spruce upland and bottomland sites. Changes in dominant vegetation types over time are shown in the arrow, beginning with nonforest (N) at 0 years post-fire and proceeding through hardwoods (H), mixed hardwoods and white spruce (MW), white spruce (WS), and, after long periods without disturbance, black spruce (BS), if sites become wetter and colder. (b) Model of vegetation cover relative to fire cycle length on white spruce sites derived from the succession pattern shown in (a).

used to demonstrate several significant changes that accompany lengthened fire cycles.

First, as fire cycles are extended beyond approximately 100 to 150 years, the proportion of hardwood cover and mixed woods decreases. In the Tanana Basin, fire cycles lengthened from 107 to 288 years over the period from 1940 to 1981. This would correspond to a decrease from 79% to 30% in hardwood forest cover on the warmer, well-drained sites, if the forest composition was given a long enough time to reach equilibrium under the lengthened cycles. Hardwood and mixed forests contain the bulk of the birch and aspen forests that provide the best sources of fuelwood in interior Alaska. Fuelwood is presently the major locally produced wood product consumed in the Tanana Basin, and demand is growing rapidly (Alaska Dept. of Natural Resources, 1983). Reductions in hardwood and mixed wood forest cover thus have serious implications for forest management and biomass production.

The second major impact is the increase in average stand age that parallels the increase in fire cycle length. Productivity declines in old stands, and even in white spruce forests 200 to 300 year old stands are well past the period of peak biomass production.

Finally, long periods without disturbance may lead to conversion of white spruce sites to black spruce sites. Black spruce stands contain less desirable tree species for either fuelwood or sawtimber and generally support slower growth rates. The average fire cycle length from the period 1970 to 1981 is estimated at 288 years, probably too short a cycle for significant site conversion to take place. This is an average figure for all forest types, however, and black spruce forests burn more frequently than white spruce. Data from the Little Chena River Basin indicate that a continued policy of active suppression of all fires could result in cycles as long as 400 to 600 years on white spruce sites.

This may well be a long enough period for black spruce cover to develop.

The changes associated with the active suppression policy are likely to decrease available biomass in interior Alaska. Increased burning is neither feasible nor desirable in all forests, however. Sites with valuable resources such as river bottom forests or populated areas are poor targets for rescinding past suppression policies. Instead, fire management plans similar to the Tanana-Minchumina Interagency Fire Management Plan (US Dept. of the Interior, 1982) should first be completed throughout interior Alaska to identify appropriate levels of fire suppression for different regions. Second, where fire suppression is necessary, intensified forest management -- including controlled burning -- may be desirable in order to reproduce some of the beneficial effects of wildfires. Finally, additional research is needed, particularly to determine the effectiveness of active forest management techniques in mimicking the desirble impacts of wildfire.

Land Disposal Policy[3]

From FY 79 to FY 82[4] the state legislature specified that 40,485 ha (100,000 ac) of land would be offered for sale each year. The amount of land actually affected by this program was in fact much greater than the net offerings indicate. Disposal projects included large amounts of unsold land within their boundaries, which, although remaining in public ownerhsip, were not available for most resource management activities such as forestry. In the Tanana Basin alone this amounted to 141,000 ha of land in the four years from FY 79 to FY 82. Disposal projects were scattered throughout the basin in many different vegetation types. However, since these lands were intended for agricultural, residential, or private recreational use, the offerings included a higher proportion of forest land than is present in the basin as a whole (Figure 4).

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[3] "Land disposal" here refers to the sale of public lands to private individuals.

[4] The state fiscal year runs from 1 July to 30 [illegible] is named for the calendar year in which it ends.

The impacts of this policy on forest management are twofold. First, lands within disposal project boundaries are removed from production. These areas are a patchwork of small privately owned parcels unlikely to be committed to timber production interspersed with public lands that are withdrawn from the land base available for forest management. In the Tanana Basin, the amount of forest land affected by the FY 79 to FY 82 disposals equals approximately 4.6% of the total area of forest land.

Second, settlement that accompanies land disposals forces the state to continue a policy of active fire suppression even in remote areas. The result of fire suppression, as already discussed, is an increase in the length of fire cycles which causes broad changes in forest vegetation. Mitigation of the negative impacts of the land disposal policy on forest management would require a decrease in the amount of acreage offered and concentration of disposals in areas of relatively low value for long term management. In addition, location of disposal areas in zones where fire suppression is already desirable, e.g., near existing developments, or where fire hazards are naturally low, would minimize problems associated with fire suppression.

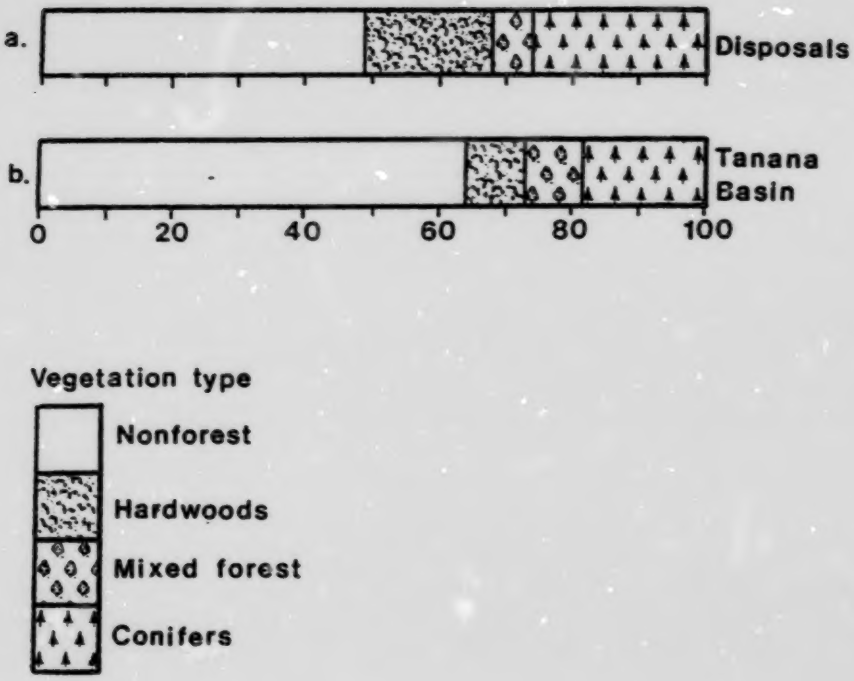

Figure 4 Vegetation types within disposal project boundaries as compared with vegetation types in the Tanana Basin as a whole.

Conclusions

The range of policies that affect forest management extends well beyond those intended to direct timber production. Analyses of the fire management and land disposal policies in the Tanana River Basin demonstrate the need to evaluate the long term effects of such policies on ecosystem processes. Understanding these effects provides the basis for designing policies that complement forest management programs.

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Potential Effects of Short Rotation Forestry
in High Latitudes
on Soils and Site Fertility

John Yarie and
Keith Van Cleve
Forest Soils Laboratory
University of Alaska
Fairbanks, Alaska

Abstract

The utilization of woody crops as an energy feedstock is gaining in importance. Current research indicates that an additional 2 - 4 quads of wood feedstocks can be produced annually by the year 2030. The environmental effects of intensified woody utilization are relatively unknown. The potential environmental effects of wood energy utilization on soils can be divided into two areas; physical and chemical.

The current forest harvesting literature describes most of the potential physical effects. If road building and harvesting techniques are matched to the site there should be little problem with adverse physical effects. The one factor found in northern latitudes which will require special attention is permafrost.

The literature on chemical or site fertility effects is varied. Site fertility effects have to be evaluated on a site specific basis. To avoid large, detailed studies of nutrient cycles on a site specific basis it is best to adopt a general model and calibrate for specific sites. By using a model as a starting point it should be possible to accomplish three tasks; (1) identify research needs, (2) establish the priority of these research needs and (3) identify sites which may be most sensitive or provide the greatest return to intensified management.

Potential Effects of Short Rotation Forestry in High Latitudes on Soils and Site Fertility

John Yarie and Keith Van Cleve

Although the oil crisis of the seventies is now part of history, one must still keep in mind the fact that fossil fuels are a non-renewable resource. To this end, many companies and private citizens are still attempting to minimize their dependence on energy derived from fossil fuels and switch to energy derived from renewable resources. These renewable feedstocks are often wood or wood chips. Increased utilization of mill wastes and wastes from whole tree harvesting for traditional forest products, currently supplies most of the chips.

The role of biomass plantations is being studied as a potential source of energy. Current research indicates that an additional 2-4 quads of wood feedstocks can be produced annually by the year 2030 (Cushman et al. 1983). The biomass plantation then represents the most intensive management of any woody crop.

The environmental effects of increased use of forest materials for energy cover a broad spectrum of management intensities. At the least intense level no additional site disturbance would be generated if only mill wastes were used from traditional forestry operations. On the very intense level, an energy plantation would be managed similar to an agricultural crop. As an example, if we compare short rotation intensive culture (SRIC) systems for energy and fiber (the two most intensive silvicultural systems devised) to a normal commercial forestry operation, a number of distinct differences can be seen (Table 1). In general, the energy plantation utilizes closer spacing, different species and a much greater amount of fertilization and early weed control. As a result, the harvest cycle for an energy plantation is much shorter than either the fiber plantation or the commercial forestry operation. There is the potential for eight energy harvests within one fiber rotation and up to 50 energy harvests in one standard commercial timber rotation.

As might be expected, this increase in intensity of management, either through increased utilization of existing stands or the establishment of energy plantations, will have far greater effects on soils and site fertility than the traditional forms of forest management. It is these potential effects that we will address in this paper.

The environmental effects of both traditional and short rotation forestry systems have received some attention and several reviews have been published (Leaf 1979, Freedman 1981, Lambany and Blouin 1980, Van Hook et al. 1982 and Kimmins 1977). The type of effects we will consider can be broadly lumped into two categories - physical and chemical. The physical site effects include soil compaction and erosion while the chemical effects are primarily deal with the nutrient cycling aspects of crop production. One additional chemical effect which is not considered here is the use of herbicides to control weed competition.

Physical Effects

Most physical site effects are the result of harvesting operations including road building to the site. Most, if not all, of the problems associated with these operations can be minimized, if not eliminated, by careful planning on a site specific basis. Lambany and Blouin (1980) have done an excellent job of evaluating the potential impacts of forest biomass harvesting and suggesting possible mitigative measures. There is no need to repeat their work but instead just to emphasize the highly erodable nature of the loess soils found throughout interior Alaska.

One area that has received very little attention is the determination of the amount of compaction that root systems of species suited to energy forestry can handle before damage and loss of coppice productivity result. Froelich (1982) has suggested that for mature trees the relative decrease in height growth is amazingly constant over a large number of studies for a broad range of percent compactions.

In almost all cases, the short rotation energy plantations will be harvested by machines. These machines will have to be designed to minimize the impact of harvesting on the soil structure and coppice root system. Currently, there is no information on the amount of damage a coppice root system can withstand before significant growth reduction occurs.

Chemical Effects

The effects of biomass harvesting on-site fertility can be accessed in two ways. First, by looking at the total amount of nutrient capital removed from the site and second, by looking at the effects of harvesting on the biologically-controlled nutrient turnover mechanisms (e.g. N-mineralization).

Nutrient capital removal studies have, for the most part, considered increased removals due to whole tree logging. Freedman (1981) has published the only analysis which attempts to compare short rotation removals with normal forestry removals for a comparable time scale.

It has been found in many studies that the standing crop of nutrients in aboveground tree biomass is generally a small proportion of the total site nutrient capital, but a much larger percentage of available soil nutrients (Freedman 1981). This also seems to be the case for northern boreal forests

(Table 2). Based on this table, it appears that there is no reason to worry about depleting the site of N, P, Ca or Mg, but potassium appears to be the one element that may cause problems. Calcium has also been reported as a possible nutrient which will quickly become depleted in certain areas of the Lake States and northeastern U.S. (Van Hook et al. 1982, and Boyle et al. 1973).

The one problem with static analyses is that it totally ignores the dynamic nature of forest ecosystems. As an example, based on the date in Table 2, one could assume that there would be a growth response to potassium fertilization. When fertilizer was applied to a young aspen stand a very definite growth response did result from nitrogen and phosphorus applications but no response was generated from potassium fertilization (Van Cleve and Oliver 1982). What we can conclude from this study is that some other ecosystem process must be limiting the supply of nitrogen and phosphorus to the plant even though there are large quantities present in the forest floor and mineral soil (Table 2). There are several ways in which nutrients can be supplied or made available to plants in an ecosystem; the most important of these are: precipitation inputs, decomposition of organic matter, and symbiotic biological fixation, as is the case with nitrogen.

The first, and easiest to access, ecosystem input is precipitation. In some instances, a large portion of the aboveground standing crop can be supplied simply by inputs from precipitation (Table 3).

A large portion of the total tree nitrogen is supplied by precipitation, but very little of the P, K, Ca, and Mg, at least for paper birch and quaking aspen. The large excess of total tree nutrients supplied for black spruce is due to the extremely slow growth rates of the species. A faster growing, more nutrient demanding species will have less of its annual requirements met by precipitation inputs.

The precipitation inputs in Table 3 represent those common in relatively unpolluted environments. The one benefit from increased atmospheric pollution is an increase in certain plant nutrients in precipitation. It is possible to raise nitrogen inputs from 1 Kg/ha to 10 Kg/ha per year when going from an undeveloped region to an area with extensive industrial development. In a study using an eleven year rotation of sweetgum in Mississippi, precipitation inputs equaled or exceeded the nutrient drain due to harvesting for N, P, K and Mg (Francis and Baker 1982) . Calcium was the only exception and then a very large pool of exchangeable (plant available) calcium was found in the mineral soil.

One of the most important sources of nutrients is from the decomposition of soil organic material and fresh litter. Again, the exact effects of changing to a short rotation crop are not entirely known. One could hypothesize that, if during site preparation, most of the organic layer is left in place or mixed with the upper mineral soil, there would be an initial fertilizer effect as the easily decomposible material releases its nutrients. This effect is commonly referred to as the "assart effect" (Tamm and Peterson 1969). After this initial flush the site may return to a fertility level at or below the preharvest level. Very little is known about the dynamic properties or duration of the assart effect.

A gradual decline in mineral soil organic matter may result, similar to that found in agricultural systems with the increased decomposition rates due to clearing; reducing site productivity in the long run. This may not be the case in energy plantations. Van Cleve and Moore (1978) found that fertilizing a young aspen stand actually increased soil organic matter, probably due to greater root turnover. Because the use of fertilizers is considered mandatory (Cushman et al. 1983) the long-term effect on soil organic matter may be quite small, but again this is one area of study that needs more work.

Some means of maintaining or enhancing site fertility will be required. If you compare a long rotation stand of mature Picea rubens - Abies balsamea - harvested at 100 years and 100-1 year rotation of a Populus hybrid growing on a similar site you see that for the mature spruce-fir stand only 239 kg ha^{-1} 100 yr^{-1} of nitrogen is removed while 8600 Kg ha^{-1} 100 yr^{-1} of nitrogen is removed with the hybrid (Friedman 1981). This greatly increased nutrient removal from the site will require that some type of system to improve or maintain site fertility be used.

Expand discussion on decomposition.

The use of nitrogen fixing plants, such as alder, to help improve or maintain site fertility has been suggested. In most cases, a mixture of alder and some other faster growing species is suggested. In an early study done by DeBell and Radwan (1979), a black cottonwood and red alder mixture yielded greater biomass than pure stands of either species. These findings are, to some degree, substantiated by work currently being carried out by Heilman (pers. comm.). After two growing seasons, Heilman found that total production was reduced when alder was mixed with high productivity clones, but increased with low productivity clones. On the average, mixtures of alder with all the black cottonwood clones tested only slightly increased production. However, if the main objective in interplanting alder is to maintain site productivity and the possible production loss is acceptable, then it appears that alder will add substantial quantities of nitrogen to the soil (DeBell and Radwan 1979). This nitrogen accretion phase may be short lived if interplanting is carried out with a high production clone. The clone tends to quickly overtop the alder and severely limit its available resources for growth, thus substantially reducing its effectiveness as a site maintenance factor.

As an alternative to interplanting with alder, fertilizer applications may be suggested as an easier means to maintain site fertility. The use of fertilizers to improve site quality does not appear to be consistent or easy to judge. Although fertilization, if used properly, can indeed increase productivity (Van Cleve and Oliver 1982) the overall concensus from the SRIC program is that it must be considered on a site-specific basis (Cushman et al. 1983). Data from a large number of studies across the country indicate that poor quality sites may be the most difficult to deal with in terms of fertilization regime (Table 4). Medium and good quality sites may yield smaller increases as a result of fertilization, but the increases and fertilizer regime may be much more consistent and easier to predict.

The one high latitude possibility for improving site quality that deserves much more attention concerns warming of permafrost-dominated soils. If a permafrost site is cleared, it should start to warm. Upon warming, all biological processes should increase, including decomposition of the existing organic layers. Because a short rotation plantation may tend to be open to solar radiation more than an existing forest the warming and increased decomposition should lead to increased site productivity over the original stand. This effect in theory should last until the site nutrient capital is depleted.

The clearing may then result in other problems that may seriously limit the sites operability. A thermokarst topography may develop that will prevent machine harvesting of portions of the plantation. It is also possible that if a substantial area is cleared and warmed that increased stream flow and possible nutrient enrichment of the stream may result. However, little is known concerning this environmental effect.

The final question that remains is how to assemble all the site-specific information for a particular site and be able to determine what effects specific management alternatives will have on the site productivity, both in the short and long term. Probably the best way to assemble data and to ascertain what information needs to be collected is by calibrating an appropriate model.

Currently, there is no need to start by writing a completely new model; there are enough examples already published. Two good examples are those developed by Aber and Melillo (1982), and Kimmins and Scoullar. Work currently being carried out in Fairbanks with FORCYTE (Kimmins and Scoullar 1979, Kimmins et al. 1980) on white spruce has resulted in a number of potential lines of research to help confirm the model's predictions on long-term site productivity. These studies would help to confirm or dispute the predictions of site degradation due to certain types of management schemes.

The use of an existing model will help to quickly show where data gaps exist. Running the model should then help to prioritize the studies necessary to fill in the data gaps and ultimately to identify sites which may be most sensitive to intensified management and conversely to identify sites which may be best suited to short rotation management.

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Table 1. Production methods for SRIC energy wood and fiber and commercial forestry.

Variable	Energy	Fiber	Commercial Forestry
Spacing	10-30 ft^2/Tree	60-80 ft^2/Tree	90-300 ft^2/Tree
Species	Hardwoods	Softwoods	Generally Softwoods
Fertilization/Weed Control	Extensive	Limited	Very Limited
Harvest Cycle	3-8 years	15-25 years	50-150 years
Land Focus	Unused Agricultural Lands	Forest Lands	Forest Lands

Table 2. Total aboveground tree plus forest floor and available mineral soil and nutrients (g/m^2) and proportions of total found in trunk and total tree (from Van Cleve et al. 1983).

Forest Type	N	P	K	Ca	Mg
		Site Total			
Black Spruce	382.3	582.4	23.7	347.5	65.7
White Spruce	384.4	410.5	57.7	829.3	161.5
Paper Birch	572.2	374.0	41.9	539.5	193.7
Quaking Aspen	336.6	252.1	54.0	450.1	88.4
Balsam Poplar	640.3	489.3	70.1	1575.8	79.7
			% in Trunk		
Black Spruce	1.33	0.12	13.1	4.52	2.13
White Spruce	2.60	0.27	15.1	4.02	3.35
Paper Birch	2.74	0.40	17.4	3.06	1.96
Quaking Aspen	4.46	0.56	21.1	9.89	3.73
Balsam Poplar	2.44	0.43	34.7	8.62	12.6
			% in Total Tree		
Black Spruce	3.22	0.24	24.05	8.20	4.11
White Spruce	7.13	0.85	42.8	8.6	3.41
Paper Birch	4.93	0.80	28.4	4.7	2.94
Quaking Aspen	7.90	2.06	35.2	15.1	6.1

Table 3. Percent of total tree nutrient supplied by precipitation (Van Cleve et al. 1983).

Forest Type	Age	N	P	K	Ca	Mg
		Precipitation Inputs g/m^2*				
Black Spruce	95	21.9	0.7	15.2	37.1	10.5
Paper Birch	77	16.2	0.5	3.9	6.2	0.8
Quaking Aspen	55	11.6	0.3	2.8	4.4	0.6
		% of Total Tree				
Black Spruce		178	50	258	130	387
Paper Birch		59	17	33	28	14
Quaking Aspen		45	11	15	7	12
		Average Yearly Input (g/m^2)				
Black Spruce		0.23	0.007	0.16	0.39	0.11
Paper Birch		0.21	0.006	0.05	0.08	0.01
Quaking Aspen		0.21	0.006	0.05	0.08	0.01

*Precipitation inputs are calculated by multiplying average yearly inputs by the stand age.

Table 4. Results from studies comparing effects of fertilization versus no fertilization on mean production[a] (from Cushman et al. 1983).

Species	State	Site quality[b]	Stand age (years)	Mean Production (dry Mg ha^{-1} $year^{-1}$) Unfertilized	Fertilized	Increase[c]
Eucalyptus grandis	Florida	P	1.4	0.2	8.9	45X
Eucalyptus saligna	Hawaii	M	2.5	0.8	21.5	27X
Sapium sebiferum	Texas	P	4.0	0.2	2.6	13X
Populus spp. hybrid	Pennsylvania	G	3	1.5	7.1	5X
Populus spp. hybrid	Pennsylvania	G	3	1.6	6.2	4X
Populus spp. hybrid	Pennsylvania	M	3	0.9	4.9	5X
Robinia pseudoacadia	Georgia	P	4	4.62	5.21	1.1X
Liquidambar styraciflua	Georgia	P	4	0.63	0.79	1.3X
Platanus occidentalis	Georgia	P	4	2.57	2.55	1.0X
Alnus rubra	Washington	P	4	6.0	7.0	1.2X

[a] Fertilization data includes several treatment levels and combinations of nutrients.

[b] P = poor, M = marginal, G = good.

[c] Yield increase as a result of fertilization.

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Forest Biomass Energy Production for the North

L. Zsuffa
Ontario Tree Improvement and
Forest Biomass Institute
Ontario Ministry of
Natural Resources
Maple, Ontario

Abstract

Forest biomass is an abundant source of energy. Trees have always been used as fuel, for cooking and heating. Even today, one-half of all trees harvested are utilized for fuel, supplying 14% of the total energy needs of humanity.

Only a small portion of the world's annual forest growth is presently utilized for industrial and fuel wood. Large areas of non-commercial forests and forest residues can be used for fuel where needed and economical. Short rotation forestry is considered for energy production where natural forests cannot supply the needed fuel. This concept of wood energy plantations is very attractive because of high yields, uniform and accessible biomass harvests. Thus, it has become a much studied proposition in many countries, including Sweden and Canada.

Sweden depends on imported oil for 80% of its energy needs. This country has undertaken a program of self-reliance in energy and envisages forest biomass contributing 46% of its total energy needs. Most of the biomass will be produced in willow energy plantations. The Swedish Energy Forestry Project is active in research and demonstration. Research includes production models, eco-physiological yield potential, species selection, mechanization, and socio-economical impacts. Demonstration is on two pilot farms, on abandoned farmland and peatland.

Canada has expanded its versatile hybrid poplar plantation program for energy production. Mini-and midi-rotation biomass plantations are suitable for northern sites, but need frost resistant, fast-growing clonal stock of poplars and willows. Breeding work for the same is in progress and shows promise.

Northern sites with potential for cultivation and utilization, and for growing poplars and willows, can be used for wood energy production. Experience and planting stock developed in Scandinavia and Canada can be applied to this purpose.

FOREST BIOMASS ENERGY PRODUCTION FOR THE NORTH

by:

L. Zsuffa
Ontario Tree Improvement and Forest Biomass Institute
Ontario Ministry of Natural Resources
Maple, Ontario LOJ 1E0

Introduction

The energy which is produced annually by photosynthesis, and stored in the form of global biomass, equals about ten times the world's annual use of energy. Most of this energy is stored in the form of forest trees. Trees have always been used as a major source of energy (Zsuffa 1982).

It is not widely appreciated that biomass supplies about one-seventh of the world's fuel. This amount is equivalent to 20 million barrels of oil a day which is twice the Saudi Arabian oil production and equal to the United States' daily oil use.

About half of the world's population relies mainly on wood for their cooking and about half of all trees cut down are used for cooking and heating. In some developing countries such fuel often comprises up to 90% of the total energy use.

In industrialised countries, where greatly increased prices and potential shortages of fossil fuels have created the need for alternate energy sources, biomass is being utilized on an increased scale, not only for heating and direct burning, but also for such diverse uses as power generation and liquid and gaseous fuels. In these areas the present contribution of biomass to total energy is of the order of 5% but several countries plan to increase this to more than 20% by the end of the century. The current world-wide, government-sponsored biomass research and development for this purpose approached $2.5 billion in 1980, and more than 80% of this money was allocated in the U.S.A., Brazil and Canada.

Forests as a Source of Biomass Energy

The largest percentage of biomass on the earth is in the form of wood in the forests, which also makes up the major portion of annual plant growth. The world's annual forest biomass growth is estimated at 9×10^{10} dry tonnes. This growth exceeds by far the quantities of wood used and it is obvious that, in addition to covering the present needs for industrial wood, the world's natural forests can make significant contributions to the energy consumption of human society.

Canada presently uses less than half of its annual forest biomass growth and only 3% of this volume is utilized for fuel. The forest inventories and growth figures show that, theoretically, the utilization of wood for fuel can be increased to much larger proportions without affecting the supply to wood industries. This applies especially to areas, such as the Yukon, where few wood industries operate and large quantities of overmature timber are available locally. In these circumstances, forest biomass can become an economically viable source of energy.

Important sources of forest biomass energy, when available, are noncommercial and overmature timber, forest logging wastes and wood industry residues. Practically, however, transportation and harvesting costs can make some of these sources less attractive and uneconomical (Carlisle, 1976).

The Production of Wood in Energy Plantations

Noncommercial forests and trees are often not available in significant quantities for energy conversion in areas where populations and industries need them and where land is available for biomass production. Such land areas, which are not competitive in terms of general agricultural production, are found in many countries. These could be advantageously converted to energy production by the establishment of wood energy plantations.

Wood energy plantations are comprised of closely spaced, genetically-improved, usually broadleaved trees which can be harvested repeatedly on cycles of less than 10 years. After each harvest of the above-ground portions of the trees, the root-stocks remain intact and resprout to regenerate the stand. Because these root-stocks already exploit the rhizosphere fully and also contain carbohydrate reserves, the new sprouts form rapidly. Soil preparation and weed control are usually needed for plantation establishment and fertilization may be needed to maintain growth. The high accumulation of biomass (annual yields of 20 dry tonnes/ha or more have been reported, surpassing by far the growth in natural forests), the uniform biomass quality and the accessibility of the land result in lower harvesting and transportation costs and better utilization of the biomass.

The potential of wood energy from short rotation plantations is well recognized; the advantages of this are as follows:

- it creates a domestic source of energy and thus maintains a security of supply and cost;
- it is renewable and all indications are that yields can be further improved;

- because of the short harvesting cycles, interest charges are lower and it has the characteristics of a cash-crop;
- it can be grown locally and provides numerous socioeconomic benefits;
- it can make more effective use of under-utilized or marginal land;
- it is flexible, and so the land can be changed, as required, to other uses;
- it is adaptable to non-energy uses as regular tree crops;
- in comparison with oil and coal, the SO_2 content of wood is relatively low;
- it is more energy efficient in the growing stage than most agricultural crops. The net energy efficiency ratio for energy plantations is usually above 1:10 for energy input-output as compared to 1:3 for most agricultural crops;
- it is ecologically sound.

These advantages, together with a ready market for biomass, have made energy plantations a much studied proposition in many countries. This is shown in the Biomass-Energy directory (Bente, 1980) which lists 35 projects in this field in 7 countries: Brazil, Canada, France, Ireland, Philippines, Sweden and USA. The Forestry Energy Program of the International Energy Agency also exchanges and develops information in the field of wood production for energy with 10 countries: Austria, Belgium, Canada, Denmark, Finland, Ireland, New Zealand, Norway, Sweden, and USA. Good examples of such programs are in Sweden and Canada.

The Swedish Program

The Swedish program is of special interest to Canada because of the similarities in latitudes, sites, and type of forests between the two countries.

Presently, Sweden imports 80% of its energy needs while fuelwood and wood-waste contribute only 8% of its total energy consumption. Sweden has undertaken a program of self-sufficiency in energy and envisages forest biomass contributing 46% of the country's total energy needs by the year 2015. This country is looking at forestry residues as a source of material, but most of the biomass will be produced in energy plantations, which will cover 6-7% of Sweden's land area.

The Swedish Energy Forestry Project is under the direction of Prof. G. Siren, University of Agriculture, Uppsala. It is probably one of the most well-known research and development projects of its kind in the world.

Creating expertise in the field of production biology and technology is the main goal of the project. Extremely high-yielding clones of several species, primarily willows, have been collected, tested and multiplied. Working hypotheses include: theoretical and practical production models, land availability, eco-physiological yield potential including site preparation and optimization, clone testing procedures, mechanization, employment, energy analysis and profitability analysis. In initial experiments, over 20 oven dry tonnes/ha/year have been harvested. Without implementing any optimization program 12-18 oven dry tonnes/ha/year have been produced so far (Siren, 1980).

To test and evaluate complete energy forestry systems, two pilot farms of short rotation forestry have been initiated. These are described by Söderberg (1981) as follows: Pilot Farm 1 is 110 ha located on abandoned farmland, and Pilot Farm 2 is 80 ha, established on unproductive peatland. The plantations are of willows, in twin rows at 0.75 m x 1.25 m spacing. The harvesting cycles are 2-3 years. Each pilot farm is composed of plantations, irrigation and fertilizer facilities, harvesting equipment, carriers and nearby strips for natural drying and storage.

Planning for both occurred in 1979-80. Pilot Farm 2 was prepared and planted in 1980-81 and Pilot Farm 1 in 1980-82. Cultivation and harvesting will continue until 1985 and evaluation will take place in 1985 and 1990.

The Canadian Program

Canada plans energy self-sufficiency by 1995. The contribution of biomass energy to the total energy consumption will be doubled in this period from the present 3% to 6% (Drysdale et al, 1983). Most of the biomass energy presently used, as well as the planned increase, is from forest residues. Non-commercial forests and wood residues are available and could supply more bioenergy, if economical and needed. Incentives are extended to the forest industry and these have resulted in moderate scale research and development programs.

The slash left in forests after harvesting operations and the presently unused forest industry mill residues are a huge source of biomass energy. They represent the equivalent of nearly 10% of this country's energy demand from material which is now available. Noncommercial and unused, overmature forests are also available in regions, especially throughout the north, and could be used for energy supply. There is also a long term potential for the production of greater amounts of biomass by growing trees in energy plantations. These sources combined might increase the total contribution of forest biomass to 25% of Canada's energy requirements (Juneja et al, 1980).

The province of Ontario's hybrid poplar program is a good example of a successful research, development and management effort in the field of wood production for energy.

In the southeastern region of Ontario, the need for more wood fiber for the local pulp and paper industry was realized in the late 1960's. This need was coupled with a good land base (which amounted to several hundred thousand hectares of abandoned farmland), and advanced poplar breeding work. This and the enthusiasm and knowledge of a group of specialists and scientists resulted in a successful program (Raitanen, 1980, Zsuffa and Anderson, 1980).

The main operational characteristics of the program are as follows. The management systems used most frequently involve short-rotation and mini-rotation poplar plantations. The short-rotation plantations are established with plain (unrooted) cuttings at approximately 3 x 3 m spacing. The rotation is about 10 years, and the objective is to produce traditional-sized pulpwood trees of approximately 20 cm in diameter and 18 m tall. Annual yields of 20-30 m^3/ha are obtained. The mini- rotation plantations are established with densely (30 x 90 cm) planted plain cuttings. One-to-three-year-old coppices are harvested repeatedly and yield 15 tonnes/ha or more of total annual oven dry biomass. Other management systems, such as a 5 to 6 year "midi-rotation", and mixed plantings of poplar and nitrogen-fixing plants, are also under investigation.

The management practices involve mechanical and chemical site preparation and tending, pest control and, when necessary and applicable, fertilization, irrigation and pruning. After harvesting, the regeneration of subsequent crops is usually by coppicing from the tree stumps left in the ground.

The matching of clones to sites, management systems and desired production quality is carefully monitored. Clones show specific reactions to the above criteria, therefore a variety of clones (approximately 100) is kept in production to satisfy the needs. Furthermore, continuous breeding and selection work secures better clones all the time.

The fast-grown hybrid poplar biomass has many uses. Initially, the production goal was pulpwood. Recently, diversified potentials have appeared for poplar biomass in the fields of energy, food and chemical feed-stock. The hybrid poplar biomass has been studied for a variety of uses, including the above mentioned, and was found satisfactory.

Biomass plantations are suitable for northern sites, but need frost resistant fast growing clonal stock of poplars and willows, well adapted to the required conditions.

Breeding work in Ontario was initiated more than a decade ago with the goal to produce northern poplar varieties. Many selections from across the prairie provinces, northern Ontario, Quebec and Newfoundland were propagated and tested, and hybrids were produced in a number of combinations using such selections. Good hybrids were produced by crossing the frost-resistant balsam poplar (Populus balsamifera) with cottonwood (P. deltoides). Over 500 clones were tested in nurseries in northern Ontario for frosthardiness and vigorous juvenile growth and outplanted in several field trials. Positive results were obtained, and we have developed more than 20 poplar clones suitable for growing conditions in the north. In nursery stool areas these clones grow at a rate similar to the fast-growing clones in southern Ontario. However, field plantations have not advanced enough as yet to allow for proper evaluation.

Willow clones and plantation technologies developed in Sweden and Finland will be of use on similar sites and latitudes in Canada. New willow selection in the Canadian north was initiated recently within the frames of international cooperation and with international support (IEA). Several hundred clones were selected and propagated and some have already been used in hybridization. This work will yield very valuable stock for energy plantations within the next 5 years.

Northern sites with potential for cultivation and utilization for growth of poplars and willows can be used for wood energy production. Experience and planting stock developed in Scandinavia and Canada can be applied for this purpose.

Yukon Perspectives

Forest biomass can be of considerable significance locally and regionally in Yukon. An interesting demonstration of this capability is the Pelly Crossing project, in Central Yukon, about 250 km north of Whitehorse (Hollbach, 1983). The community has a population of about 200, and a new school has just been built with a wood-chip boiler. The cost of a year's fuel for the wood-chip boiler is about one-quarter of the cost of a year's fuel oil supply. The Yukon Department of Education has contracted the Selkirk Indian Band to provide wood chips. The most obvious benefit of the wood-chip boiler to the community is jobs. The agreement provides for financial assistance to the Band members in the use and operation of these boilers. The agreement has also assisted the installation of two, smaller wood-chip boilers in Band-owned buildings in Pelly Crossing. Once again, these conversions will provide work and will keep money circulating in the community that would have otherwise paid for oil.

Such demonstrations may encourage the conversion of commercial and institutional heating systems. The local economic impact of biomass use, and the greater diversification of energy sources, makes the increased use of biomass an attractive goal.

In parts of Yukon, such as in close proximity to Whitehorse, there is an abundance of natural timber. It is not used extensively by any industry and is available for energy conversion.

The production of biomass for energy, if and when needed for local projects, is feasible as well. The establishment of a demonstration planting (of limited size) would be of advantage for eventual future application of this concept.

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Vegetative Propogation of Alnus Crispa

Michael U. Stoehr
Robert E. Farmer Jr.
School of Forestry
Lakehead University
Thunder Bay, Ontario

Abstract

Six experiments over the course of the 1982 growing season were conducted with physiologically juvenile and mature *Alnus crispa* cuttings to test the effects of hormone treatment and collection data on rooting. In two of these experiments the juvenile cuttings were taken from shoots sprouting from the base of mature stems. For the four other experiments, juvenile cuttings were taken from shoots that were induced by pruning mature stems in the spring of the same year. Juvenile cuttings rooted significantly better than mature cuttings. Rooting was highest (92%) for juvenile cuttings collected on August 25 and treated with 1.0% indolebutyric acid (IBA) in 50% ethanol for 5 seconds. Mature cuttings generally rooted poorly. Best rooting (46%) was observed when the mature cuttings were collected on July 29 and treated with a mixture of two fungicides (Captan and Benlate) and 1.0% IBA and 1.0% 1-phenyl-3-:methyl-5-pyrazolone (PPZ) in talc.

Vegetative Propagation of *Alnus crispa* (Ait.) Pursh.

by

Michael U. Stoehr and Robert E. Farmer, Jr.
School of Forestry
Lakehead University
Thunder Bay, Ontario, P7B 5E1

Introduction

Interest in the genus *Alnus* L. has increased simultaneously with recognition of the potential of nitrogen fixing plants in intensive forestry (Gordon & Dawson 1979). Green alder (*Alnus crispa* (Ait.) Pursh), the most abundant nitrogen fixing upland shrub in Canada's boreal forest, is probably the single most important contributor to nitrogen stocks in jack pine (*Pinus banksiana* Lamb.) and black spruce (*Picea mariana* (Mill.) B.S.P.) communities. Its population biology and ecological role are therefore worthy of research attention. Green alder may also have some potential for short-rotation energy plantations, though its small size relative to other alders suggests use in mixtures with other species. For example, in a study conducted in Rhinelander, Wisconsin, hybrid poplar clones showed significantly increased height growth when interplanted with European black alder (*Alnus glutinosa* L.). Further, the heights of these poplars were comparable to those obtained from optimal nitrogen fertilization in pure poplar plots (Hansen and Dawson 1982). Green alder may also have potential in reclamation of mine soils and other disturbed sites in the north.

Our study was aimed at development of vegetative propagation techniques which will allow cloning for experimental use. The only previously reported propagation trials with green alder were those conducted in Alaska by Holloway and Zasada (1979), who observed rooting of less than 1 percent for both hardwood and softwood cuttings.

MATERIAL AND METHODS

Six experiments over the course of the 1982 growing season were conducted to determine effects of collection date and hormonal treatments on rooting of mature and "rejuvenated" cuttings.

About one-half of the mature stems (i.e. stems bearing male catkins) in green alder clumps growing 15-20 km north of Thunder Bay, Ontario (Lat. 49°N, Long 89°W) were severed near the base in early spring 1982. This pruning caused prolific sprouting at the root collar soon after spring bud break. The resulting "rejuvenated" shoots were used as juvenile cuttings in Experiments 3 to 6. Since these sprouts were too succulent for cuttings early in the growing season, juvenile cuttings for Experiments 1 and 2 were taken from 1981 wood on young basal shoots that developed naturally in 1980 or 1981. Equivalent wood was taken from mature stems. In Experiments 3 to 6, greenwood cuttings of current shoots were used. Cuttings for each test were collected from six clumps with the exception of Experiment 6, which included cuttings from ten clumps. All cuttings were 10-12 cm long. Cones and male flowers were removed from mature cuttings.

Rooting treatments are listed in Table 1. The rooting medium was peat-vermiculite-perlite in a ratio of 1:1:1 in Experiments 1 through 5, and 1:1:2 in Experiment 6. The basal 2 cm of each cutting was dipped into the rooting chemicals. All cuttings assigned to powder treatments were wetted first to enhance the adhesion of the rooting powder. Cuttings assigned to the ethanol-IBA treatment were kept dry and dipped for five seconds. Prior to the application of the rooting hormones, cuttings in Experiments 4 to 6 were soaked in a 5.0% henomyl (Benlate) slurry for 2 to 3 minutes.

Cuttings were planted 2 to 3 cm deep into preformed holes in the rooting medium, which was held in plastic flats (52 cm long x 10.5 cm wide x 6 cm deep). Flats were placed in greenhouse mist benches, where the mist was regulated by an "electrical leaf" device. Temperature in the greenhouse ranged from 20°C to 30°C during the day and from 15°C to 20°C at night.

In all six experiments, a 2 x 4 factorial design (two cutting types x four chemical rooting treatments) was used with four-cutting plots replicated six times in randomized complete blocks. Each of the six blocks in Experiments 1 to 5 contained only one clone, thus confounding blocks with clones; in Experiment 6 several clones were used per block. Cuttings were examined after 6 weeks in the mist bench. Arc sine transformations of rooting percentages were subjected to an analysis of variance for each test. Treatment means were compared with Duncan's New Multiple Range Test.

RESULTS AND CONCLUSIONS

In Experiments 1 to 3, fungal infection of the basal part of many cuttings reduced rooting; the fungicide treatment seemed to be effective in Experiments 4 to 6 especially in the well aerated rooting medium of Experiment 6. Best rooting (92 percent) was observed for juvenile cuttings collected on August 25 (Experiment 6) and treated with IBA applied as quick dip. For mature cuttings, best rooting (46 percent) was found for cuttings collected on July 29 (Experiment 4) and treated with the IBA-PPZ mixture (Table 1). The IBA treatments significantly increased rooting compared to the control in Experiments 1 and 6, but no single treatment was consistently superior. Juvenile material rooted better than mature shoots at all collection dates, especially later in the growing season when the sprouts were more lignified. In Experiment 2, cuttings from two clumps failed to produce any roots, which resulted in a highly significant difference (.01 level) in rooting due to blocks. In the remainder of the tests, block (i.e. clump) effects were not significant. Some rooted cuttings were potted and placed in a greenhouse where they renewed shoot growth and developed normally.

The results of this study indicate that green alder from the Thunder Bay, Ontario area can be successfully propagated vegetatively if rejuvenated cuttings are treated with IBA. The ability to clone green alder allows simple evaluation of genetic variation in growth rate, shade tolerance, and nitrogen fixation, all important characteristics in use of alder under intensive management in species mixes.

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ACKNOWLEDGEMENT

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Table 1. Effects of chemical treatment and collection date on rooting percent of juvenile and mature green alder cuttings

Treatment	Rooting Percent											
	Experiment 1 (June 1)		Experiment 2 (June 23)		Experiment 3 (July 13)		Experiment 4 (July 29)		Experiment 5 (Aug. 11)		Experiment 6 (Aug. 25)	
	Juvenile	Mature	Juvenile	Mature	Juvenile	Mature	Juvenile	Mature	Juvenile	Mature	Juvenile	Mature
0.8% IBA[1] + 5.0% Captan in talc	46	12	-	-	-	-	-	-	-	-	-	-
1.0% IBA + 5.0% Captan in talc	-	-	38	8	50	8	83	29	79	4	67	0
1.2% IBA + 5.0% Captan in talc	54	8	-	-	-	-	-	-	-	-	-	-
1.0% IBA + 1.0% PPZ[2] + 5.0% Captan in talc	-	-	29	17	67	35	71	46	67	21	79	0
1.0% IBA in 50% ETOH (quick dip)	29	4	38	21	45	25	75	25	46	0	92	0
5% Captan in talc (Control)	0	0	17	0	56	17	75	0	17	0	38	0
Mean	32	6	30	12	54	21	76	25	52	6	69	0
Mean of IBA-treated cuttings	43	8	35	15	54	23	76	33	64	8	79	0

[1] indole-3-butyric acid

[2] 1-phenyl-3-methyl-5-pyrazolone

Assessment of the Economic Impact of a Wood Fuel Industry

R.J. Brandon
G.W. Mason
IEA Consulting Group Ltd.
Charlottetown, PEI

Abstract

This paper presents a review of recent demonstrations and activities in wood fuel technology in Prince Edward Island. There are some demographic similarities between the Yukon and P.E.I. such as a small population and limited secondary industry. The regions also have forest resources with low utilization and dependence on oil for space heating requirements.

Recent analysis of the economic impacts of a potential wood fuel industry on P.E.I. may have some conclusions that are also relevant in the Yukon. The study group used a simplified Delphi approach to determine the structure of a wood fuel industry in 1990. With this structure the primary and secondary economic impacts on the provincial economy were determined. These impacts include job creation, tax generation and subsidy displacement.

As an example, the recent installation of a 3 million BTU/hr. woodchip fueled heating system in a hospital in P.E.I. is examined and the economic viability of this installation presented. The initial performance of the unit indicates that the $360,000 project has an internal rate of return greater than 16% with an annual job creation potential of 1.1 manyears. Additional benefits will also be discussed.

Introduction

While on opposite sides of the continent and having quite different climate and topology the Yukon and Prince Edward Island share certain simularities. Both regions have small populations with their own jurisdictions. The majority of dwellings in both locations are heated with oil that is imported to the respective regions. Both regions are forested but there are few commercial forest operations because of the distance to markets.

In Prince Edward Island the primary industries are farming and fishing with tourism and government also making an important contribution. In the Yukon, the government and the service sectors provide the majority of employment followed by mining and construction.

Table 1 details employment by major sector and Table 2 summarizes the statistics of both regions that are pertinent to this paper. Space heating requirements are provided predominately from fuel oil that is imported to the region and unemployment is high in both regions.

Use of Wood as Fuel in P.E.I.

As in most rural areas of Canada, wood has historically been used for home heating purposes and was only replaced in the fifties with the availability of inexpensive oil. In the seventies, with the rapid increase in oil price, a return to the use of wood as a fuel has been evident in Prince Edward Island. This has been monitored by three surveys carried out under the Canada - P.E.I. Agreement on Renewable Energy. The results of

Table 1

Percentage of Employment by Sector

	Yukon	P.E.I.
Mining	10.3	--
Manufacturing	--	6.0
Forestry	.2	.2
Construction	7.8	3.5
Service	30.0	48.9
Public Admin./Gov't	40.5	8.8
Communication, Transportation & Other Utilities	5.2	6.3
Trade	--	11.7
Agricultural & Other	--	14.6
Total employed	8,893	48,000

Table 2

Comparative Statistics

	Yukon	P.E.I.
Population	23,153	122,800
Unemployment	17.6%	13.1%
Forest Production		
(Roundwood)	54,000 cu.m.	60,400 cu.m.
(Cordwood)	41,200 cu.m.	390,000 cu.m.
(Lumber)	14,200 cu.m.	100,000 cu.m.
#2 Fuel & Propane	49,000,000 litres	123,000,000 litres*
% Residences Oil Heated	76.4%	74%
Price Home Heating Oil	39.0 cents/litre	32.0 cents/litre

* Light fuel oil only

Sources: Yukon Residential Energy Survey EM&R 1983
Yukon Economics Review 4th Quarter
Province of PEI Annual Statistical Review 1982

these surveys are shown in Table 3. The results show a significant increase in the use of wood in Island homes. The wood is used in stoves or central heating systems of conventional design and has caused an increasing number of chimney fires because of creosote problems caused by these designs. In order to determine if the use of chip wood or pellet wood was feasible in small dwellings, a demonstration was undertaken in 1979 by the Institute of Man and Resources under the Canada - P.E.I. Agreement. Thirty wood chip burners were installed in rural homes and twenty-four wood pellet burners installed in urban homes. The results of the work have been reviewed (Energo 82) and the conclusion reached was that the use of chipwood was feasible and the greatest advantages were increased homeowner convenience and reduced creosote formation. Pellet fuel was also found feasible but the cost of the fuel processing made this alternative uneconomic for P.E.I. at this time.

It has been estimated by a recent survey (Canada - P.E.I. Forest Development Agreement), of the forest resource that the annual allowable cut is 1,120,000 cubic meters. The cover type of the 247,000 ha of stocked forest is subdivided into the categories shown below:

Cover Type	Ha	%
Softwood	90,313	37
Mixed (Predominately Soft)	33,310	13
Mixed (Predominately Hard)	52,907	21
Hardwood	70,537	29

While fuelwood already makes up a significant proportion of the harvest, expansion of this component is viable and can generate substantial benefits for the Island economy. These benefits include displacing foreign oil with cheaper energy that generates local employment, increases provincial economic activity and is also environmentally acceptable if efficient combustion equipment is used. The related light industrial spinoffs may also be significant. With this in mind, a study into the economic impacts of a wood fuel industry was commissioned in 1980. However, a current concern exists that the demand for round hardwood fuel may start to have a negative impact on the forest hardwood resource. There is also concern about smoke emissions in urban areas from roundwood burners.

The Economic Case for Wood Fuel

Concurrent with the technical development of better combustion systems, it was recognized that a full examination of the economic case for substituting wood for oil fuel should be determined. It is recognized that such a change in infrastructure would not occur overnight since experience has shown that the transition from coal to oil as a heating fuel took ten or more years in the Atlantic region. The transfer from a convenient liquid fuel to a less convenient solid fuel will take even longer. It was expected that if fuel oil was displaced by wood fuel there would be significant benefits to both the provincial and federal governments that would warrant them encouraging the substitution. At the time of the study in 1981, the federal government funded oil subsidy program was one substantial cost that a wood fuel industry would reduce. With the current oil glut, some of these potential federal government savings have been reduced or eliminated; however, many of the conclusions reached in the course of the work remain valid and may also be applicable to the Yukon situation.

Assessment of the Economic Impacts of a Wood Fuel Industry in P.E.I.

Design and Objectives

The study having the above title was commissioned by the Institute of Man and Resources, a local research institute, to Middleton Associates of Toronto. The objective of the work was to postulate a viable wood fuel industry structure that might exist in 1990. Pro forma income statements were then drawn up for each of the industry segments. The overall employment, production, capital requirements and tax flows were determined. The impact on the existing fuel oil infrastructure was determined. By simulating the new industry the value of this local fuel industry was determined and the estimated annual tax returns determined for both the provincial and federal governments. These figures could be used by government to justify investment in the expensive combustion systems that industry and homeowners would need to use wood fuel. It was also hoped that the information would be useful to governments to compare the advantages of investing in a wood fuel infrastructure from a job creation viewpoint.

Table 3

Use of Wood Fuel in Residential Dwellings

	1979-80	1980-81	1981-82	1982-83 (projected)
Average wood fuel consumption per dwelling using wood fuel	3.60	3.90	4.64	4.89
Total Volume (cords)	72,000	79,000	104,700	110,000
Households using wood fuel (thousands)	19.4	23.3	23.8	
Percentage of Total Households	54.4	62.0	60.4	

Table 4

Estimated Wood Fuel Consumption (000 cu.m)

	1980	1983	1990
Residential	255	389	507
Commercial Industrial Government	--	4.0	226
Electric Utilities	--	--	116

Table 5

Wood Fuel Industry Requirements

	Production Capacity (000 cu.m)	Labour (man years/cu.m.)
Woodlot Owner Harvester	0.18	0.7
Small Woods Contractor	5.4	0.45
Large Woods Contractor (Roundwood)	10.6	0.26
(Chips)	18.0	0.12
Dealers (Medium)	7.0	0.2

Methodology

The Institute developed the industry structure based on interviews with local experts and its own in-house expertise. A schematic of the proposed industry is shown in Figure 1. Of course, the only aspect of predicting the future is the certainty that one's prediction is wrong; however, carrying out the assessment proved very instructive and a consensus was not difficult to achieve. Individuals from the Provincial Forestry Department, Energy Department, homeowners and businessmen were used to obtain the schematic.

Middleton then proceeded to analyze both the current energy situation and the proposed industry in 1990. The assumed price for fuel oil in 1990 was 35 cents per litre in 1980 dollars compared to 16 cents per litre at the time when the study was done. The current P.E.I. fuel price of 34 cents per litre is equivalent to approximately 25 cents per litre in 1980 dollars. Wage rates in the study were assumed to be $9/hr.

Study Findings

A wood fuel industry that supplied 980,000 cu.m. of wood fuel annually would be viable and would not adversely affect the forest resource. The industry would displace approximately 106 million litres of oil. The major end users of this industry are shown in Table 4 along with current estimates of activity. The amount of substitution is expected to be 40% of the current space heating requirements of the residential and service sectors of the economy. It is expected that increased energy conservation will enable this percentage to be substantially increased.

PROJECTED WOOD FUEL INDUSTRY FLOW CHART - 1990

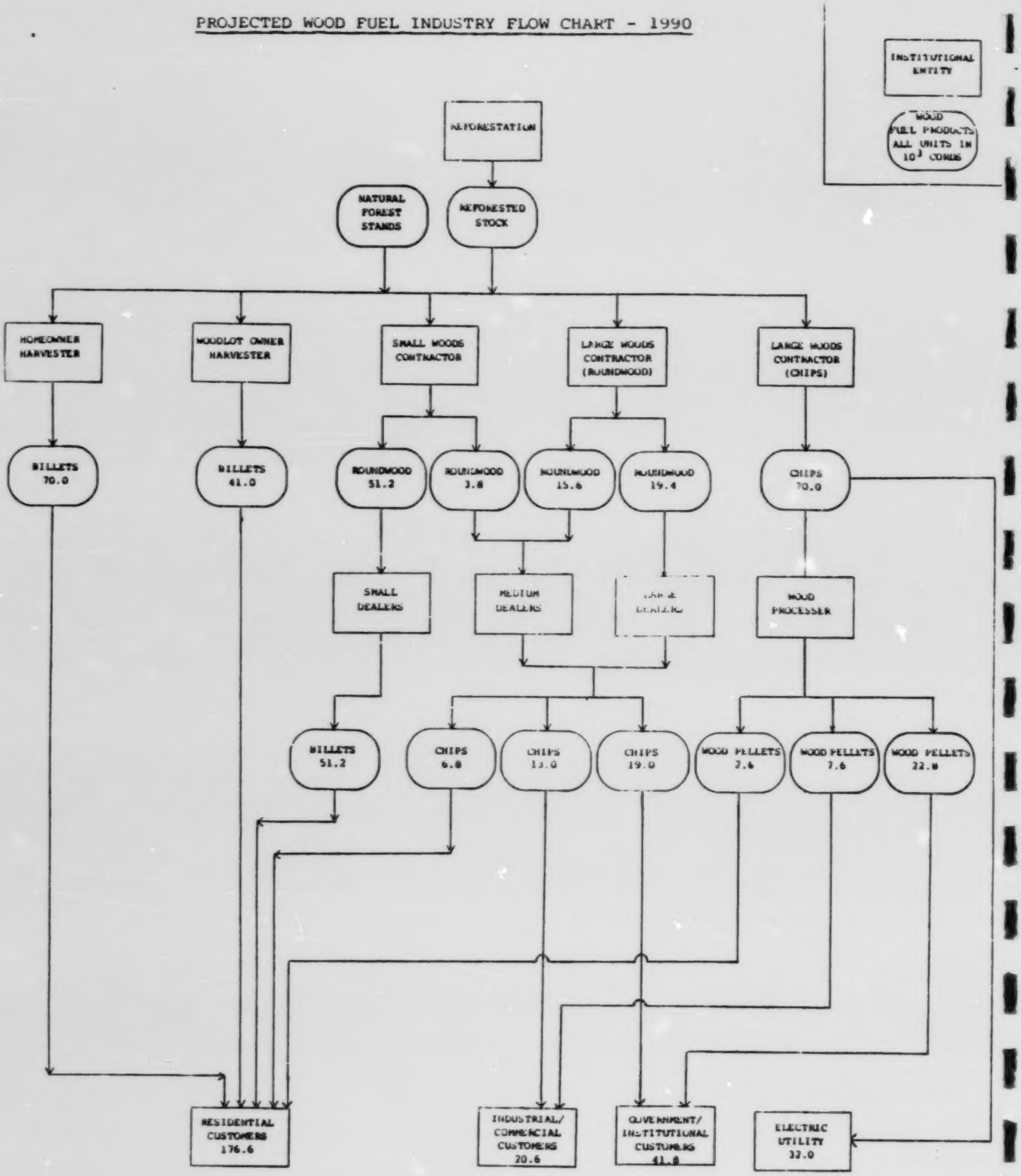
INSTITUTIONAL ENTITY
WOOD FUEL PRODUCTS ALL UNITS IN 10³ CORDS
REFORESTATION
NATURAL FOREST STANDS
REFORESTED STOCK
HOMEOWNER HARVESTER
WOODLOT OWNER HARVESTER
SMALL WOODS CONTRACTOR
LARGE WOODS CONTRACTOR (ROUNDWOOD)
LARGE WOODS CONTRACTOR (CHIPS)
BILLETS 70.0
BILLETS 41.0
ROUNDWOOD 51.2
ROUNDWOOD 3.8
ROUNDWOOD 15.6
ROUNDWOOD 19.4
CHIPS 70.0
SMALL DEALERS
MEDIUM DEALERS
LARGE DEALERS
WOOD PROCESSER
BILLETS 51.2
CHIPS 6.8
CHIPS 13.0
CHIPS 19.0
WOOD PELLETS 7.6
WOOD PELLETS 7.6
WOOD PELLETS 22.8
RESIDENTIAL CUSTOMERS 176.6
INDUSTRIAL/ COMMERCIAL CUSTOMERS 20.6
GOVERNMENT/ INSTITUTIONAL CUSTOMERS 41.8
ELECTRIC UTILITY 32.0

Figure 1

Excluding the labour of homeowner harvesters the wood fuel supply industry would generate 355 manyears of employment or 0.36 manyear per 1000 cu.m. of capacity. Various segments of the industry are more labour intensive and a breakdown of these is given in Table 5. At the present time a number of small woodlot contractors and co-operatives form the bulk of the industry. In 1990 these small firms are still estimated to form the majority of employment opportunities.

A negative employment effect of 35 man-years was estimated for the oil fuel distribution industry along with the tax revenue losses on the sale of fuel oil. On balance, the industry, if in existence, would generate $1.4 million in annual net benefits to the provincial government. This is comprised of 62% in corporate tax, 36% in personal income tax and 2% in stumpage fees for crown land. The federal government could obtain an annual net benefit of $3.1 million of which 76% comes from corporate tax and the balance from personal income tax.

Not estimated in the study were savings to the federal government associated with unemployment insurance and oil compensation savings although these could be substantial. It would appear therefore that both levels of government could receive $6100 in corporate and income taxes for every thousand cu.m. capacity in a substantial wood fuel industry. An assumption of course would be that these tax revenues could be obtained in an industry in which tax payments have been rare on the Island. This aspect requires further analysis. However the case can be made that both levels of government stand to gain from investment in a wood fuel industry. The study showed that the value added in the wood fuel industry is 90% compared to 10% for the fuel oil industry of which the only local component is the labour needed for distribution.

The study did not address the capital cost implications. The capital cost requirements, excluding combustion systems, was estimated to be $12 million. Based strictly on a capital budgetting analysis, the Federal and Provincial governments should be willing to spend $75 million in capital cost grants to achieve the $4.5 million annual revenue generation (assuming a 6% real rate of return).

One year after the study was completed, planning was started on installing a heating plant using wood fuel at a local hospital. This plant was monitored by IEA Consulting Group for the P.E.I. Energy Corporation, a provincial energy agency. The performance of this plant can be compared with some of the economic estimates produced from the study.

The Montague Hospital Project

In October, 1981, the P.E.I. Energy Corporation established a project under the Canada/P.E.I. Comprehensive Development Plan to convert the heating system of the Kings County Memorial Hospital (KCMH) in Montague, P.E.I. to a wood chip fueled system. The hospital previously consumed 450,000 litres of light fuel oil on a year round basis.

Capital Costs

The conversion required the construction of an addition to house the new boiler and provide storage space for weekly supply of wood chips (approx. 50 tonnes or 145 cu.m.). The furnace was supplied and installed by Anga and Varme Canada Ltd. The heating unit generates 3 million BTU/hr. to fire a 125 psig conventional firetube boiler. The system first went into operation on May 8, 1982 with the oil fired boilers in the hospital acting as backup.

The total investment at the hospital was $362,000 for the building addition, the furnace and the related modifications. The capital was broken down approximately into:

Local Labour	$100,000
Local Materials	$ 41,000
Engineering Fee that could have been local	$ 25,000
Imported Resources	$196,000
TOTAL	$362,000

Notice that the above indicates an incremental impact of approximately 5 manyears of employment plus related spinoffs during the startup period.

Fuel Costs

The initial evaluation by IEA Consulting Group covered a one year period from May, 1982 to April, 1983. Wood fuel was obtained from one contractor who used a number of different stumpage sources and fuel-delivery systems. The unit consumed approximately 2070 tonnes of wood at an average moisture content of 49.5% for the one year period.

The wood fuel was contracted at a standard price based on a 40% moisture content. The price was adjusted to allow for the actual moisture content. The fuel price averaged out to $28.39/delivered tonne for a total fuel cost of $58,760.

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Operating Costs

The wood chip furnace was essentially automatic and required little more attention than the oil units. Basic maintenance included raking the ashes to the removal augers and clearing the occasional jammed fuel auger. Because one maintenance engineer is required for either the oil or the wood system, there is no incremental labour cost.

There is an incremental electrical cost associated with the electric motors driving the augers, the fans and peripheral equipment. The annual electrical costs was recorded at $4,000 for 39,840 Kwhr (at $.10/Kwhr).

The wood chip furnace supplied heat during the 1982/83 winter, equivalent to an estimated 392,000 litres of fuel which would have cost $120,000 (at $.305/litre). The relevant cost comparison is therefore:

	Oil	Wood
Fuel	$120,000	$59,000
Electricity	--	4,000
Total	$120,000	63,000

The analysis indicated a savings in fuel costs of $57,000 per year.

Capital-Budgetting Analysis

The total investment at the hospital was $362,000 which produced a first year savings of $57,000 or a simple payback of 6.4 years.

A capital budgetting analysis was carried out assuming:

1. A useful life of 20 years
2. Wood prices increase at 6%/year
3. Oil prices remain constant for 3 years and then increase at 6%/year
4. Electricity expenses increase at 8%/year
5. Discount rate of 12%

The resulting present value of the savings is $498,000 which results in a positive net present value of $136,000 for the project. The internal rate of return for the investment is 16.7%, making it relatively attractive.

Employment Impact

The wood fuel sales of $59,000 included a variable labour and supervisory content of approximately $28,000. It could therefore be expected that for every dollar spent by consumers on wood chips, approximately $.50 would go directly to local labour. This compares with a figure that is probably less than $.05 for oil.

The fuel production process directly generated approximately 1 man year of labour. The addition of supervisory time and spinoffs would increase this figure slightly so that each 400,000 litres of oil displaced could generate 1.1-1.2 man years of employment (net). The exact amount depends on the nature of the production process and the local employment multiplier. The Montague chip contractor used both capital and labour intensive production systems so the figure represents a reasonable average.

This result indicates that 0.17 man years of employment are created for every thousand cubic metres of wood fuel production. This is in line with the 0.12 man years per thousand cubic metres of chips estimated for the large wood contractor in the earlier study.

Forest Industry Impact

The hospital could easily be supplied with fuel from a 245 ha woodlot on a sustainable basis. This would result in the application of forest management to that amount of land. Because of the nature of wood chip fuel, the greatest benefits are realized in converting non-commercial forest lands and in improving existing stands. With most of the forest land on P.E.I. under private ownership, this could provide a means for economic stand improvement and forest establishment.

Environmental Aspects

The unit was found to be clean burning with negligible smoke emissions. Reference to the concern about the impact of acid rain in the region indicates that the substitution of high sulfur oil by efficient wood combustion units would be environmentally beneficial. The cleaning out of dead and damaged forest areas to allow for reforestation would also be beneficial from an environmental standpoint.

Conclusions

The work carried out in P.E.I. might have some relevance to development of a wood fuel industry in the Yukon. In particular, it has been shown that government should consider other aspects of provincial economic activity when determining the level of support for construction of wood combustion systems. Over and above the fuel savings there is the creation of employment principally during the winter months of 0.2-0.45 man years per thousand cubic metres of wood fuel depending on the size of the industry. The experience at the Kings County Memorial Hospital suggests that installations of this size are marginally attractive when viewed in traditional economic terms. However, since the activity in the wood fuel industry would generate an extra tax revenue this would on its own justify a government investment in a plant and equipment.

A more detailed analysis looking at the savings derived from the reduction in unemployment payments and the increased Provincial value - added in fuel production would increase this figure.

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Wood Residues
Enterprising Energy

E.T. Owens
New Brunswick
Research and Productivity Council
Fredericton, N.B.

Abstract

The elements of an industry based on wood-for-energy are supply of raw material, demand for an alternative to fossil fuel, a manufacturing industry to produce associated equipment, a marketing and distribution infrastructure and information transfer.

Identification of the specifics of supply and demand is a primary step, followed closely by the employment opportunities in making combustion units and distributing fuel. Inherent in this procedure is an initial decision on the type of fuel to feed this emerging industry.

Obviously the program must be made known to the public - so audio and visual media forms are used extensively and imaginatively.

WOOD RESIDUES - ENTERPRISING ENERGY

by
E. T. Owens, R.P.F.
N.B. Research and Productivity Council

Energy sources in the past half-century were commonly perceived as fossil fuels and hydro, with nuclear reactors a distant third -that is until the early 1970's. OPEC changed the perceptions and caused latent movers and shakers to realize that there are alternatives to oil for heating and fueling industry and homes.

A principal alternate source and a renewable resource as well, is Wood.

A province like New Brunswick quite logically considers its forest as a primary generator of employment and a substantial contributor to the continuing economic well-being of its citizens. The province is 85% forested and the forest products industry provides direct employment for more than 14,000 people. Any additional demand upon the wood resource must be considered in the context of the existing industry.

Recent analyses of the forest inventory and the allocation of raw material to secure 14,000 jobs led to the conclusion that quality material must continue to go the routes to veneer, lumber, pulp and paper and specialty products. However, the residues from processing standing trees into primary and secondary products are available for a variety of uses. An important use is energy generation.

Studies completed by government and industry have determined that the province has reached the limit of sustained softwood harvesting if no silvicultural treatments are undertaken. The hardwood component has a substantial surplus although not in higher value material such as veneer bolts and sawlogs.

Numerically industry needs 7.6 million m^3 of softwood annually, of which 6.9 million m^3 come from provincial forests; 0.3 million m^3 is exported; and 1.0 million m^3 is imported. The hardwood annual allowable cut is 2.68 million m^3 of which existing industrial capacity can utilize 1.73 million m^3. A further 0.5 million m^3 is allocated for roundwood fuel, leaving 0.45 million m^3 as surplus. These data are conditioned by market oscillations and general economic activity but they illustrate broadly the basic situation.

Recognizing the physical and economic constraints of establishing a program based on roundwood, it was decided to explore the use of residues to build a wood energy industry. An initial step was examining available data. An informal study by the Department of Commerce and Development showed that sawmills had residues - defined as bark, sawdust, shavings and unbarked slabs - which were used to a maximum of 50% of availability in 1980. However, it was projected that by 1984 there would be a demand for 125% of available residues. The actual dates may not coincide with the predicted deficit but there is no doubt that within two years there will be a residue deficit.

The obvious source to offset the residue deficit is harvesting and a brief examination of this operation showed a theoretical supply of more than enough to feed the industrial, institutional and residential furnaces and stoves.

Other Considerations

In formulating a complete Wood Energy Program it was essential to have all elements move in parallel and be coordinated.

Such a program was made possible through the Canada/New Brunswick Conservation and Renewable Energy Demonstration Agreement (CREDA). A series of projects was put in place by funding from this Agreement and incorporated into an integrated plan of operations spanning an initial three years.

Preliminary studies on demand for equipment and fuel indicate reasonable viability for an industry in New Brunswick. An infrastructure for producing, storing and distributing wood residues is beginning to take shape. Impetus will be given to this aspect following the results of a feasibility study completed in early summer of this year. Augmenting the feasibility study are three other projects which will demonstrate the economic availability of wood residues from harvesting and will establish the methodology for integrating conventional wood harvesting with residue production.

It is of singular satisfaction that four New Brunswick manufacturers of equipment - three residue burners and a chipper - are testing the marketability of their products directly or indirectly under the program. A major objective of CREDA is commercialization of the demonstrations and the projects involving equipment manufacturing are of considerable importance in illustrating this objective.

Currently the thrust of the program is towards using chips as fuel in institutional and residential settings. Perhaps a more visual type of fuel is sawdust because of the ubiquitous piles of this material throughout the countryside. Sawdust is wholly dependent upon the lumber industry and a quick reference to the past few years shows the inconsistent nature of its level of operation and, ultimately, sawdust availability. Chips can be produced independent of other operations and from wood which has limited, or no other market outlet. In the ensuing years silvicultural operations, notably thinning and site preparation, will be a particularly reliable supply source.

Handling of chips and automatic stoking of chip burners are felt to be more convenient than other forms of wood fuel according to owners of home heating systems using this particulate fuel. Remarkably few problems have been experienced by two professors at the University of New Brunswick who have used chip burners in their homes since 1979.

Information Transfer

This is a burgeoning technology and informing all and sundry of its advantages, potential and problems is a formidable undertaking. It was our strategy to maintain a relatively low profile in the initial stages of the program but with a planned production of publications, audio-visual cassettes, workshops and conferences to keep pace with the successfully developing demonstrations.

To date two regional workshops have featured the use of chips and sawdust for commercial and institutional heating as alternatives to oil heating. Three booklets or brochures and three final reports of completed projects have been published. It should be noted that these publications are available in the province's two official languages. Project summaries of the 14 projects within the Wood Energy Program are in the printing process - nine having been published at this time - and periodic articles for local and provincial journals are standard.

A quarterly journal of the Energy Secretariat is in the final stage of production and the first issue will be devoted exclusively to wood residues. Two video cassettes explaining specific application of chips to a greenhouse-nursery enterprise and sawdust for heating a 5-building college campus have been produced to round out the information transfer portion of the program.

Chip Problems and Potential

The foregoing has covered the wood residue field broadly. Now the focus will be on CHIPS, since this is the most popular, both currently and potentially.

Sawmills have been producing chips from low grade and non-lumber material for decades and chippers are commonplace in municipalities for reducing unwanted parts of trees to chips. The move to use chips for fuel, other than at wood processing plants, is relatively recent. It is developing at a reasonable rate consistent with guaranteed sources of supply, improved burners and recognition of its advantages by insurance and safety organizations.

The availability of supply was mentioned previously but a chicken-and-egg scenario is apparent. On the one hand a householder may be awaiting an assured supply of chips before acquiring an automatic chip stoker. On the other hand the prospective chip supplier awaits stronger signs of a stoker market. One stoker manufacturer in New Brunswick arranges chip supply when he installs his equipment. To date he has eight in operation and local chip sources have varied from a rented mobile chipper producing fuel from a woodlot to purchasing fuel in bags from a stationary unit located at a post-secondary school. There have been no supply hang-ups to date and none are foreseen since several entrepeneurs are exploring costs and equipment with the objective of operating a particulate fuel supply business.

A considerable degree of risk and estimating will be removed from chip production integrated with conventional wood harvesting systems when the results of two industrial scale projects are made known in early 1984. The determination of the economic availability of harvesting residues and the completion of flexible models containing all elements of a wood energy industry will demonstrate potential viability for aspiring owners.

Automatic chip stokers are convenient and have proven reliable under a variety of conditions. Current developments include automatic start-up for a fire through electronic or other means and mechanical feeding from storage to chip burner hopper. Because of relatively complete combustion there is a minimum amount of ash and performance efficiency is comparable to oil burning installations.

There does appear to be some reluctance or hesitancy on the part of the insurance industry to endorese this innovation in heating and understandably so. One of the approaches to overcome such apprehension is reasonably frequent exposure of successful chip burning facilities to that industry's executives. In concert with operational tours the national organizations setting standards are made aware of the trends and their cooperation is sought in the evolution of safe, economic and convenient applicances.

This developing use of wood residues, principally chips, for energy generation is moving apace and it is our confident belief it will have positive economic and social benefits, particularly at local levels.

Projects in Operation

1. The Wood Energy Program is demonstrating the technology of wood residue combustion in residential, institutional and industrial settings. The major industrial scale user is the Northeast Energy Services Ltd. operation located on the campus of the University of New Brunswick and designed to use 45,000 tons annually of bark essentially, although other residues may be used. The burner will generate 60-65% of the energy needed to heat and light the university, a 400 bed regional hospital, an apartment complex and a government repair facility. The wood residues will replace 6.75 million litres of Bunker "C" oil annually and the estimated annual savings are $600,000; this results in a simple payback period of four years. Among the salient features of this demonstration are the use of bark for fuel; the regional concept of fuel supply (the source is five area mills within a 60 km radius); the integration of the wood-fired plant with the oil-based system; and the successful conclusion to encourage replication in other parts of Canada.

2. Two other large scale projects are associated with pulp mills and demonstrate the economics and mechanics of integrating conventional harvesting with chip fuel production. In one instance a Boise Cascade Canada Ltd. project is determining the efficient methodology for harvesting sub-marginal stands by offsetting the cost with chipping non-commercial residues. The project uses men with power saws to fell the trees, extracting pulpwood from the softwoods as appropriate and chipping the branches. As well the hardwoods, being non-commercial species or sizes,

are chipped wholetree. The resulting chips are blown into a container which is transported to roadside and dumped into a waiting truck. The fuel will displace 1.3 million litres of oil and will reduce fuel costs $160,000 based on harvesting cost and yield estimates. Extrapolated to a total replacement of oil by wood residues there is a forecasted simple payback of four years. The further incentive of undertaking this project is to determine the silvicultural benefit resulting from Full-Tree Harvesting and reduced site preparation. The monitoring plan will record the original biomass and the residuals after harvesting and chipping. The site is to be planted with bare root stock and indications to date are there will be no additional preparation needed for the planters to do their work.

3. A complementary project in northern New Brunswick with Fraser Inc. will demonstrate the production of chipped fuel as an integral part of a conventional fully mechanical Full Tree operation. The stands are mixedwood and the operation is proceeding in two phases -the softwoods are removed to roadside, limbed and piled, with the branches concentrated in separate piles; when the tree lengths have been sent to the nearest sawmill, the branches are chipped and sent to the company pulp mills; the second phase involves the removal of the hardwoods, which is also a Full-Tree operation; these trees are chipped at roadside and trucked to the pulp mills for energy generation.

On a corporate basis this demonstration is estimated to return the investment of new hog fuel burning facilities within five years.

As in the Boise Cascade Ltd. project the silvicultural benefit will be additional to the fuel cost saving.

4. Projects in the Institutional/Commercial sector include a regional correction centre, two homes for handicapped citizens, three educational institutions and a large greenhouse-nursery.

The Madawaska Regional Correction Centre uses a 3:1 ratio mixture of sawdust and chips to provide heat and domestic hot water for the centre. The total annual supply required is 550 tons which is delivered by a local sawmill at an average 1983 cost of $15.00 per ton. The simple payback period is expected to be five years.

A day centre operated by the Woodstock chapter of C.A.M.R. will use 50 tons of chips per year for heat only in its workshop. The facility produces pallets and other wooden items. The burner is a gravity-feed, thermostatically controlled unit whose fuel is supplied by a county wood producers' association.

A larger institution for adult handicapped located near Arthurette in northwestern New Brunswick is heated by three sawdust burners linked in parallel. The fuel comes from a nearby sawmill and 120 tons are needed for a normal heating season. The forecasted payback period is six years.

College St. Louis Maillet at Edmundston added a residence to the sawdust-burning heating system in 1982. The consequent oil displacement will result in a 2.8-year payback based on fuel savings of more than $31,000 per annum.

The wood chip boiler at the Maritime Forest Ranger School, Fredericton, uses 700 tons of fuel each year to heat two dormitories, an administration-teaching building and two other small structures. Improvements made in the system last year will return the investment in slightly more than two years. A unique feature of this demonstration is the complete utilization of the non-commercial wood from the University of New Brunswick forest within which the school is located. An on-site chipper prepares the fuel from the non-commercial material and it is stored in an adjacent building.

A new regional high school, being completed in south central New Brunswick, will have a chip-burning plant to provide heat and hot water. The fuel supply tender was awarded to a regional wood producers' cooperative on a three-year contract which will guarantee 544 tons annually. The system will be operational in November of this year.

A greenhouse nursery at Newcastle uses 700 tons of chips in a retrofitted system to heat some three acres of flower and plant growing facilities. The total capital cost of the retrofit was of the order of $90,000 and the anticipated annual fuel savings of $30,000 provides a simple payback of three years. The owner uses a small chipper to reduce purchased short wood (8' length) to fuel and stores it next to the heating plant. A combination of pneumatics and front-end loaders supplies the day bin from the major storage shed.

5. There are seven residential chip burning furnaces being monitored in the province - five of them in the Fredericton area and two in Bristol. The results of four years of operation of two burners owned by Professors Schneider and Short are reported in a recent publication of the Energy Secretariat while the final report on the other five awaits the completion of the coming heating season. The units, with one exception, use chips locally produced and average 10 tons per year. One burner, part of the five Woodcans made in New Brunswick, uses spruce and pine cones for fuel. The cones are obtained from the central forest seed extraction plant and have given practically trouble-free heating in the past year. To date, no significant problems have been experienced with these residential units and the future appears particularly promising.

SUMMARY

A coordinated program of projects based on wood residues to be used in generating heat for homes and industry is operational in New Brunswick. The funding for the program is through the federal-provincial CONSERVATION and RENEWABLE ENERGY DEMONSTRATION AGREEMENT. The objective of the program is to commercialize the demonstrations and there are current examples as well as encouraging indications of the objective being met.

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Densified Fuel from Land Clearing Biomass; and Long-Term Chip Storage for Fuel--Interior Alaska

George R. Sampson, Forrest A. Ruppert
and
Jenifer H. McBeath[1]

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ABSTRACT

Unusable tree and moss residue from land clearing in interior Alaska was collected, milled, dried, and densified into fuel log form. Four different species combinations were tried, and all produced suitable fuels. Feasibility of a commercial facility to convert this material into a densified fuel is limited by unsatisfactory long-term storage characteristics of the product and high ash content for moss material.

Winter chipped white spruce placed in a large open pile did not stay frozen over the long term in interior Alaska. After a portion of the pile warmed to 5°C and warmer, microbial activity provided heat up to 50°C to melt adjacent chips and warm them to about 5°C when self-heating activity began.

Keywords: Timber residue, energy, wood utilization, wood chips.

This paper reports on two separate, but closely related studies. The first is a nearly completed study of the potential for densifying biomass, from land clearing, for use as a home heating fuel. The second is a study initiated in January 1983 on the potential for long-term storage of wood chips.

Densified Fuel from Land Clearing Biomass

Purpose of Study

The purposes of this study were to determine: (1) if a densified fuel could be made from typical land clearing residue from interior Alaska; and (2) the characteristics of such a fuel if it could be successfully produced. The question of whether or not it is feasible to produce a fuel from land clearing residue is important since there are plans to have 500,000 acres (202,000 hectares) of interior Alaska land cleared for agriculture by 1990. Virtually all of this land is covered by forest and moss.

The majority of the biomass present in a typical lowland black spruce (*Picea mariana* (Mill) B.S.P.) stand is in the moss layer. One alternative to complete or near-complete on-site burning is removal and utilization of the biomass as a fuel (Eakin 1979 and Lewis 1979). This would probably require that the biomass be chipped on-site and be dried and densified at a nearby location. A major unknown was whether the kinds of biomass present on a typical site could be successfully processed through a commercial densifying operation to produce fuel logs or briquettes. Most of the commercial wood densifying operations in existence today use dry sawmill or plywood residue as a raw material.

Methods

Four types of material were selected for study. These included: (1) the moss layer under a typical black spruce stand; (2) whole tree black spruce; (3) a moss-black spruce mixture; and (4) a paper birch (Betula papyrifera Marsh)-aspen (Populus tremuloides Michx.) mixture. All materials were collected on or adjacent to the Delta Agricultural Project (figure 1). The moss layer, which actually includes all organic matter in the forest floor above mineral soil, was collected by hand in an undisturbed black spruce stand to prevent inclusion of soil and stones. Black spruce trees were taken from material in berm rows that had already been chained and piled. Whole trees were taken, including attached roots, needles, twigs, and bark. For the paper birch-aspen sample, whole trees were taken including bole, bark, twigs, and leaves, but excluding roots.

Each type of material was kept separate for hammermilling and drying. The residue was shipped by barge and truck from Alaska to Washington State University at Pullman for hammermilling and drying. All materials were chipped and then processed through a small industrial size hammermill. Wood chips were hammermilled with a 9.5 mm screen. Three different particle sizes were produced from the moss samples. Coarse moss was material that did not pass through a number 4 Tyler screen size designation (sieve with 4.75 mm openings). Medium moss was material passing through a number 4 screen, but not a 32 screen (sieve with 0.5 mm openings). The third size, designated "fine moss" was that passing through a number 32 screen. After hammermilling and screening, all materials were shipped to Fourply, Incorporated, at Grants Pass, Oregon for densification.[2] Combinations of material from different species were made at Grants Pass and were based on a nearly-dry weight basis (about 10% moisture content). The moss-black spruce mixture was 70% moss and 30% black spruce. The paper birch-aspen mixture was 60% paper birch and 40% aspen.

The material combinations tried represent situations likely to be encountered in land clearing in the interior. The moss-black spruce mixture represents black spruce underlain by a thick layer of moss. It would be possible to harvest either the moss or black spruce separately. Other lands to be cleared are covered by mixed stands of paper birch and aspen with little moss present beneath the stands. The most appropriate way of utilizing this timber is to shear it at or near ground line, taking the total tree above this point.

All material was processed through a commercial fuel log machine, a Hausmann Briquettor manufactured by Fred Hausmann, Ltd. of Basel, Switzerland.[3] In this process, a 3-inch (75 mm) diameter continuous log is extruded into a long cooling line. At the end of the cooling line the continuous log is broken into 10-inch (254 mm) lengths by a pneumatic device, and the individual logs are carried by conveyor belt to the packaging area.

Samples of each type experimental fuel produced, along with samples of the commercial product being produced at the plant, were sent to the University of Washington at Seattle for determination of calorific values and residual ash content. Samples of the experimental fuel logs were given to interested individuals for burning in their home wood-burning stoves or fireplaces.

These individuals were given a questionnaire which asked them to subjectively compare the experimental fuel logs with their usual fuel. Samples of each type fuel log were placed in both covered and exposed storage in the Fairbanks area to determine long term deterioration rates.

Results

The fine moss material that passed through a number 32 screen did not process well due to excess friction in the cooling line at start-up. However, the fine moss processed satisfactorily when mixed with wood particles or larger size moss material. There were no technical problems in densifying the other kinds of materials. Characteristics of the fuel logs produced during the test run are summarized in table 1. Weights per fuel log are greatest for moss, followed by moss-spruce, spruce, then birch-aspen. This is a direct reflection of density of the parent material.

Table 1. Weight of fuel logs produced during the test run.

		Weight per Fuel Log		
Type of Material	Fuel Logs Weighed	Range	Average	Coefficient of variation
	number	-------Ounces (grams)--------		percentage
Birch-aspen	30	45-46 (1276-1304)	45.5 (1299)	1.1
Black spruce	30	46-48 (1304-1361)	47.1 (1335)	1.2
Coarse moss	30	51-57 (1446-1616)	53.4 (1514)	2.7
Medium moss	30	53-60 (1502-1701)	56.4 (1599)	2.6
Moss-black spruce	30	51-56 (1446-1588)	53.3 (1511)	2.8
Fine moss [1]	-	-	-	-
Commercial product[2]	15	44-46 (1247-1304)	44.7 (1267)	1.1

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[1] No full-length fuel logs were produced from fine moss due to excess friction in the cooling line.

[2] The commercial product was produced from a mixture of Douglas-fir, ponderosa pine, and white fir veneer and plywood trimmings.

Table 2. Higher heating values and ash content of samples from fuel logs.

Type of Material	Test Samples	Higher heating value		Ash Content	
		Average	Coefficient of Variation	Average	Coefficient of Variation
	number	BTU/lb[1] (joules/kg)	--------percentage-------		
Birch-aspen	32	8690 (20.2 x 10^6)	1.6	1.5	33.3
Black spruce	32	8770 (20.4 x 10^6)	0.6	1.7	47.1
Coarse moss	32	6730 (15.6 x 10^6)	2.7	24.8	8.5
Medium moss	32	6430 (14.9 x 10^6)	6.5	29.7	3.0
Fine moss	06	4500 (10.5 x 10^6)	23.6	47.8	4.4
Moss-black spruce	32	6930 (16.1 x 10^6)	4.5	24.1	18.7
Commercial product[2]	31	8780 (20.4 x 10^6)	4.4		

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[1] Values rounded to nearest 10 BTU/lb (0.1 x 10^6 joules/kg).

[2] The commercial product was produced from a mixture of Douglas-fir, ponderosa pine, and white fir veneer and plywood trimmings.

The maximum potential energy or higher heating values of samples from experimental fuel logs are shown in table 2. Black spruce is highest at about 8800 BTU's per pound (20.4×10^6 joules per kilogram), followed by birch-aspen at 8700 (20.2×10^6), moss-black spruce at 6900 (16.1×10^6), coarse moss at 6700 (15.6×10^6), medium moss at 6400 (14.9×10^6), and fine moss at 4500 (10.5×10^6). Table 2 also shows ash content which is inversely related to energy content. The energy and ash content values obtained are approximately what was expected with the exception of the moss. The decreasing energy content and increasing ash content as moss particle size decreased were apparently the result of increased mineral content, principally soil.

Individuals who burned some of the fuel logs in their home heating systems liked the non-moss fuel as well or better than their usual firewood. However, they generally did not like the fuel logs containing moss as well as their usual fuel due to the slow burning rate and high ash content.

The fuel logs survived humid conditions several days on an ocean barge without adverse effects. However, fuel logs stored over winter in covered but unheated storage expanded linearly 25 to 30 percent with the advent of summer temperatures. We believe that this was caused by a combination of high relative humidity and repeated freezing and thawing. Generally, the spruce fuel logs showed greatest expansion followed by paper birch - aspen, and then the fuel logs derived from moss material. These elongated fuel logs often break when handled, thus affecting their suitability as fuel for hand feeding a home heating system. Logs placed outside remained intact after a light snow when temperatures remained well below the melting point. However, a rain initiated rapid disintegration. Therefore, covered storage and transport of fuel logs is essential at all times, and the possibility of holding fuel logs for longer than one year without deterioration is not known. Fuel logs stored in heated space have not shown a tendency to disintegrate.

A recently completed study concluded that none of the current commercial processes for densified biomass fuel without a binder can produce a product that can be stored exposed to the weather 60-90 days (Levelton and Associates Ltd. 1981).

Discussion

Collection and processing for this study involved much hand labor and were not typical of practices that would be employed by a commercial operation. A commercial operation would likely involve chipping directly from berm piles. Care would have to be taken to avoid pushing soil and rocks into the berm piles. Proper clearing technique requires leaving about 2 inches (50 mm) of moss layer behind when piling. This remaining moss is then incorporated into the soil during tilling. Thus, if land clearing is properly done, there should be a minimum of free soil and dirt in the berm piles. Some soil and rocks may cling to tree roots after uprooting but most of this would be dislodged and screened out in the chipping process and would not be a factor in densification. However, there is a substantial quantity of mineral matter incorporated in the moss layer in the Delta Junction, Alaska area which cannot be removed by any known practical means. This is a result of wind-blown particles taken from glacial stream beds and deposited in trees and filtering into the moss layer over many decades. This incorporated soil did not appear to directly affect either chipping or densification, but it gave the densified moss a black coal-like appearance. The major disadvantage of the incorporated soil is the large proportion left as residual ash after burning. The high residual ash in moss is undoubtedly a function of geographic location. Preliminary tests of moss from the Little Chena River drainage northeast of Fairbanks indicate only 3 to 7 percent residual ash.

Material left in berm piles for more than one year will undoubtedly begin to decay. However, this decay is not seen as a problem in either chipping or densification although a slight reduction in energy content of the total biomass volume will occur.

The problem of decompression and subsequent disintegration of fuel logs stored in unheated storage over winter could be avoided by shrink wrapping in groups of 2 to 4, but only at significant cost increase. The tendency to decompress and disintegrate might be less of a problem with pellets. However, expansion of fuel pellets in a bin from which a stoker system operates could present feed problems. Care would have to be taken to ensure that the atmosphere around storage bins be quite dry.

Production costs of making fuel logs from land clearing residue are largely dependent on assumptions about what equipment is going to be purchased and layout for labor efficiency. Obviously, an enclosed, heated building is essential for interior Alaska. In addition to a chipper and trucks for hauling chips, a hammermill, drier, and densifier are needed. A shed for storing fuel logs is also essential. The most efficient operation that we can envision within the size constraints imposed by local markets would require a capital investment of over 750 thousand dollars. This operation would produce more than 15,000 tons per year of densified fuel logs (less than 1/4 of the current annual consumption of firewood in Fairbanks-North Star Borough). Total costs of field chipping, hauling, and manufacture would be in the range of 55-65 dollars per ton. This would make the densified fuel logs very cost-competitive with firewood, which currently (1983) commands a delivered price of more than $100 per cord in the Fairbanks area.

Conclusions

The feasibility of commercial production of densified biomass from land clearing remains questionable unless some acceptable method for preventing decompression of fuel logs stored over winter is found.

It does not appear to be feasible to densify the moss layer where it has a high mineral content such as the 25 to 30 percent found in the Delta Junction area. Moss from areas not subject to prevailing winds carrying silt from glacial stream beds may be suitable for densification into fuel logs, but this material was not tested in this study.

The fuel logs could be only marginally price competitive with coal for home heating systems in the Fairbanks area or other areas where coal can be brought in by rail. Densified fuel logs can be very price competitive with dried, cut-to-length firewood.

Long-Term Chip Storage

Although densifying biomass from land clearing may not be practical at this time, problems of disposing of the biomass remain. It is conceivable that future technological developments will make it feasible to use such land clearing biomass for liquid or solid fuel. If the biomass could be stored for a long period of time, some of the burning disposal costs could be avoided, and the biomass may have some value in the future.

There are two other reasons for investigating long-term storage of wood. Some remote villages are interested in using wood for fuel in generating electricity. Also, farmers could use wood as a fuel for grain drying. In both cases it would benefit the users if the wood could be stored for long time periods. Chippers and chipping crews could be shared more easily among a number of users if a two year or more supply of chips could be produced at one time.

Storing the residue in its natural form (tree length or long length) is impractical because of stacking and piling problems. Densifying the residue and storing it in ready-to-use form may also be impractical because of the added cost. The most efficient way of handling wood for long-term storage is to chip it. It is likely that if chips are warm enough when they enter the pile, biological acticity will proceed at the same rate in interior Alaska as in warmer climates with the possibility of spontaneous combustion (Allen 1968, Bergman and Nilsson 1979, Springer and Hajney 1970). The possibility tested in this study was that the major part of a large chip pile would remain frozen year around in a climate such as interior Alaska, if chipping were done in the winter. If this were true, wood chips could be stored for years in a frozen state without significant deterioration.

Methods

The raw material for this study included whole tree white spruce (Picea glauca (Moench) Voss) thinnings from the University of Alaska arboretum near Fairbanks (about 10 percent of the total volume) and white spruce tops from a commercial timber sale along the Tanana River west of Fairbanks. The white spruce trees and tops were chipped with a portable chipper on the site where they were to be stored. The chips were placed in a circular pile 20 feet (6 meters) in diameter, 20 feet (6 meters) high. Chipping was done from January 15 to February 15, 1983. The chip pile was maintained in a circular shape by using snow fence anchored by four poles. Most chipping was done while the ambient temperature was -12°C to -18°C. All wood chips were frozen when they entered the pile.

Twenty-five thermocouples were placed in the pile at specified locations so that temperatures within the pile could be monitored over time (figure 2). Ten gypsum blocks were placed in the pile so that changes in moisture content could be determined. Nylon mesh bags containing approximately one-half cubic foot of chips each were placed in 15 locations within the chip pile. These bags will be removed at the time the pile is broken up, and extent of chip deterioration will be determined. Calorific value per unit of dry weight of chips will be determined at the time of pile break-up for comparison with calorific value for white spruce chips that have not been subjected to decay. Time of pile break up is scheduled for the spring of 1985. The pile will be broken up before that time only if it is judged there are problems of spontaneous combustion or the mechanical structure of the pile fails.

Results to Date

Dramatic temperature changes have occurred within the chip pile (figure 2,3,4,5,6). Shortly after completion of the pile, temperatures were relatively uniform with only an 8°C difference between the extreme thermocouple readings. On May 12th thermocouple 21 reached 0°C. On June 1, a small portion of the pile was warmer than air temperature for the first time. By June 27, the upper portion of the pile had warmed considerably while the lower portion was still cool. However, by August 12, the pile appeared to have stabilized temporarily with a hot (60°C)interior and warm exterior.

Moisture content at monitoring positions within the pile has changed very little, remaining at the 85 percent to 95 percent level (dry weight basis) at which the wood chips entered the pile.

It can be concluded that open piles of green wood chips in interior Alaska can heat up and begin to undergo deterioration regardless of whether chipped in winter or summer. In our experimental pile the heating cycle was obviously delayed for frozen chips, but when a part of the pile reached about 5°C, the temperature behavior from then on was similar to that for chip piles from freshly cut wood (White 1980).

This conclusion does not necessarily preclude storing chips for long periods of time in interior Alaska, but precautions may have to be taken. For example wood chips could be dried to 20 percent moisture content and placed in a covered pile (Springer 1979). Another option is to put the chips in a pile with vertical ventilators at two foot intervals. The results of placing thousands of tons of frozen biomass chips in open piles, as would be the case for large-scale land clearing, is speculative and more data from our experimental pile will be helpful.

FOOTNOTES

1. The authors are respectively, Research Forester, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station; Forest Resource Development Specialist, USDA Forest Service, Alaska Region State nad Private Forestry, and Assistant Professor of Plant Pathology, University of Alaska.

2. Trade and company names are used for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by the U.S. Department of Agriculture to the exclusion of others that may be suitable.

3. This machine is operated by Fourply, Inc. of Grants Pass, Oregon. Their cooperation made this study possible.

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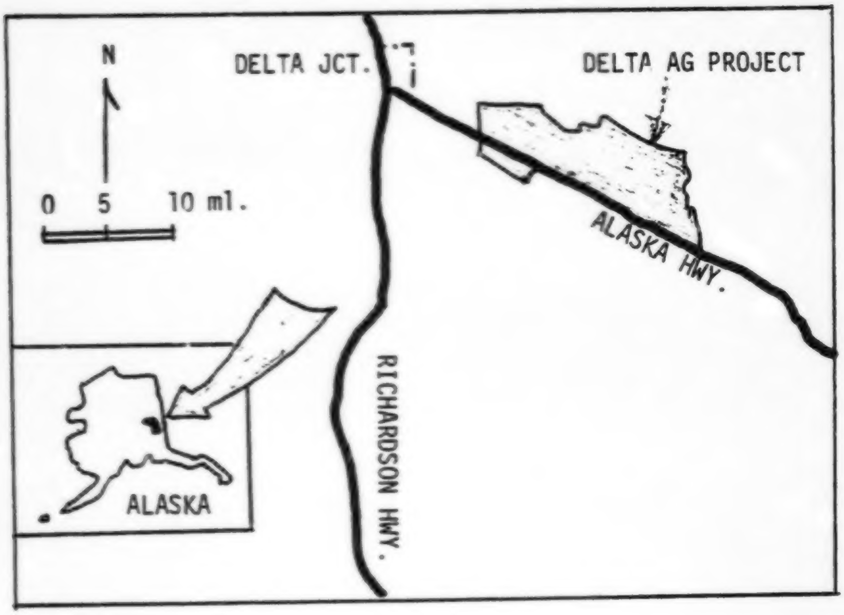
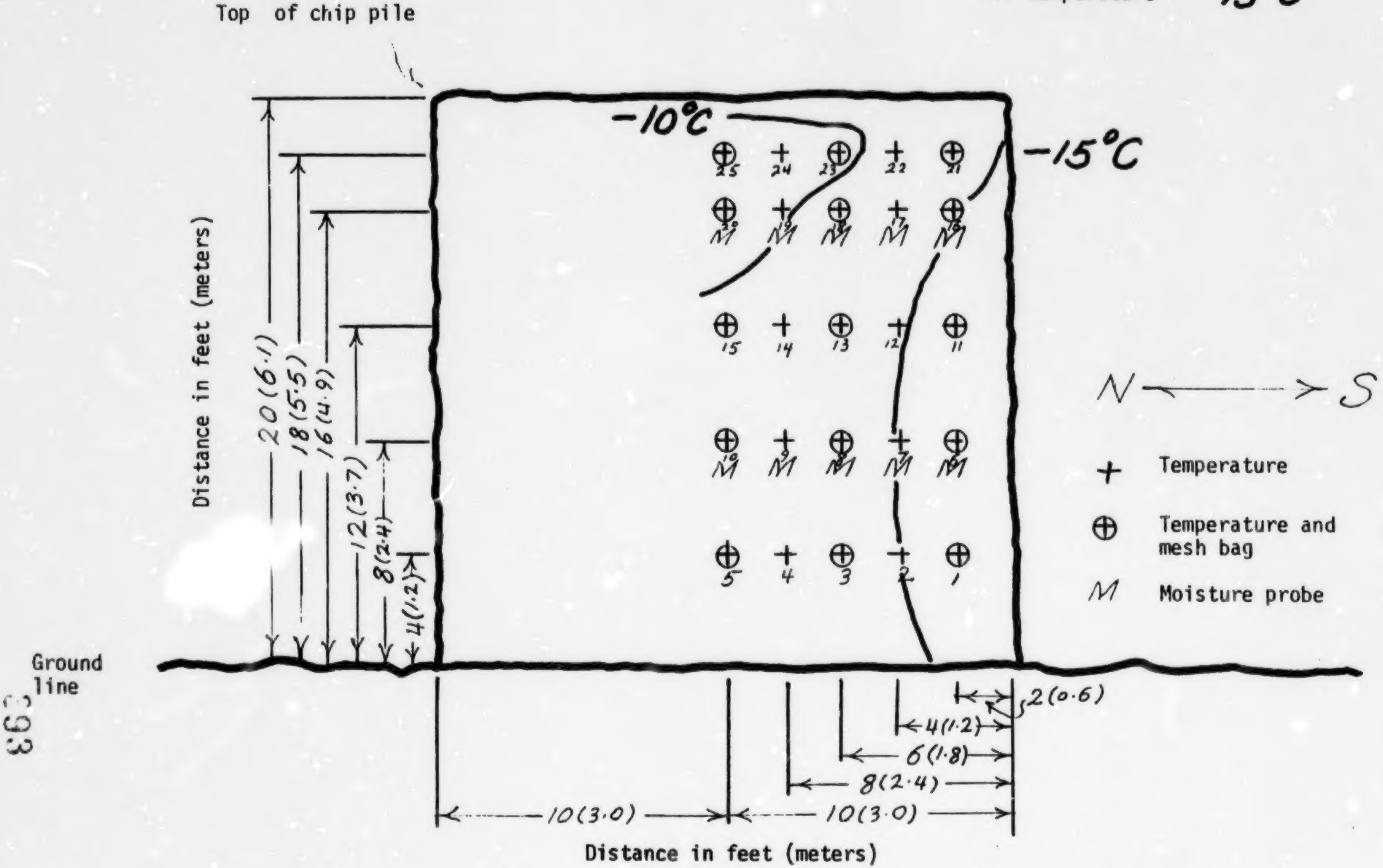

N
0 5 10 mi.
DELTA JCT.
DELTA AG PROJECT
ALASKA HWY.
RICHARDSON HWY.
ALASKA

Figure 1. The Delta Agricultural Project--source of land clearing residue for the study.

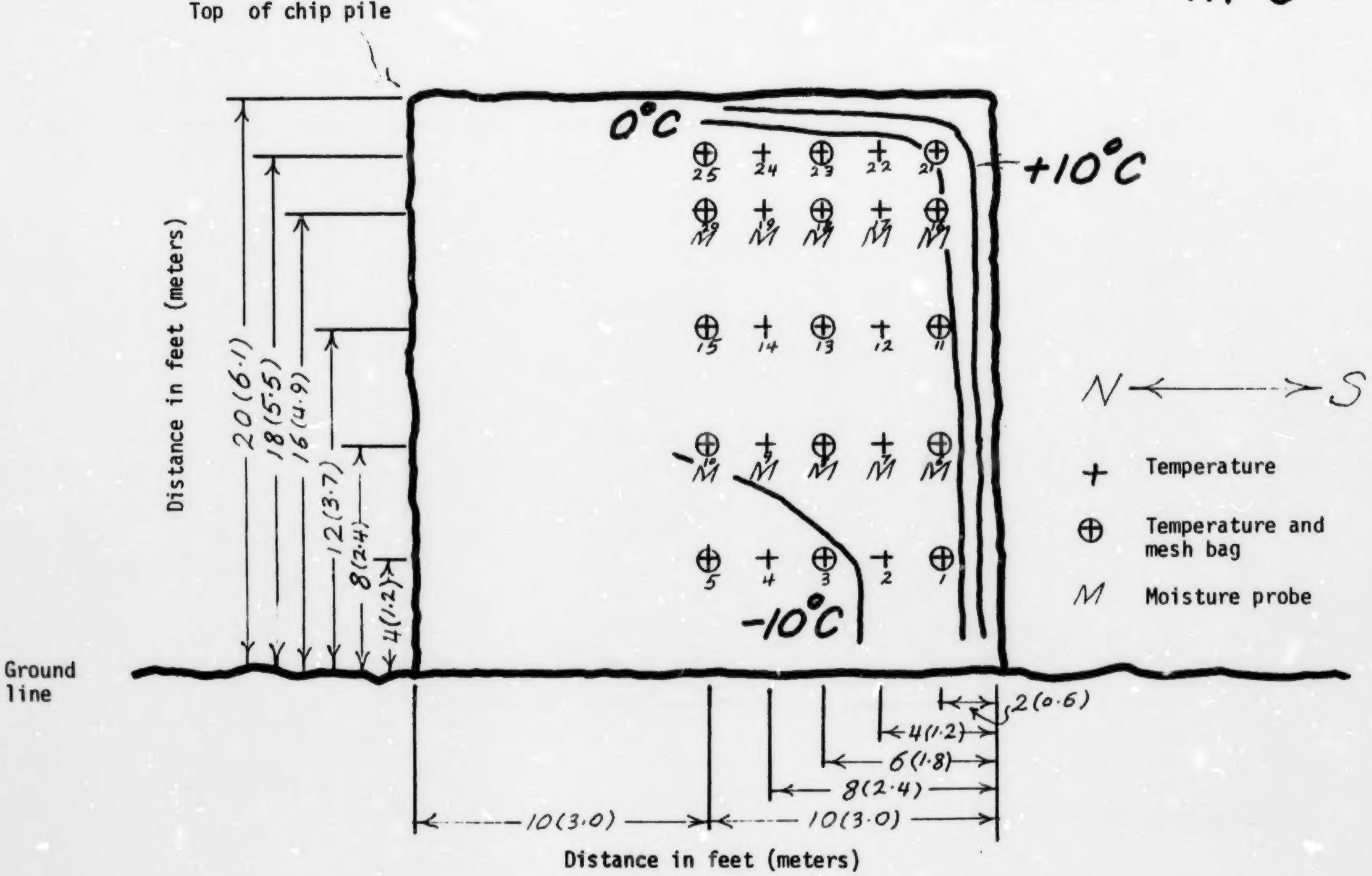
Figure . Temperature profile of wood chip pile on 2-22-83.


Air temperature = −15°C

Top of chip pile
−10°C
−15°C
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
N → S
+ Temperature
⊕ Temperature and mesh bag
M Moisture probe
Distance in feet (meters)
20(6·1)
18(5·5)
16(4·9)
12(3·7)
8(2·4)
4(1·2)
Ground line
2(0·6)
4(1·2)
6(1·8)
8(2·4)
10(3·0)
10(3·0)
Distance in feet (meters)

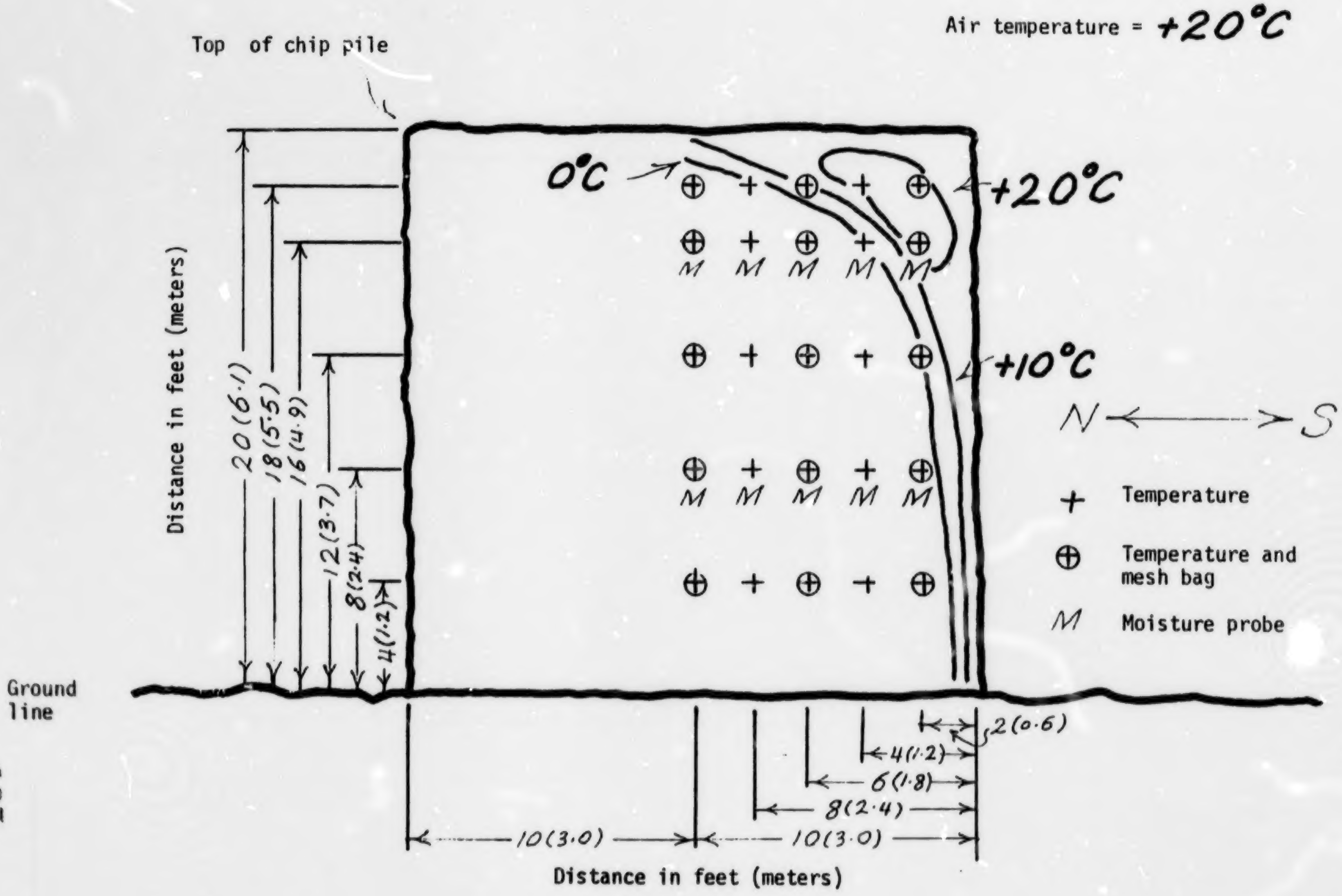
Figure . Temperature profile of wood chip pile on 5-12-83.

Air temperature = +17°C



Top of chip pile
0°C
+10°C
-10°C
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
M
N
S
+ Temperature
⊕ Temperature and mesh bag
M Moisture probe
Distance in feet (meters)
20(6.1)
18(5.5)
16(4.9)
12(3.7)
8(2.4)
4(1.2)
Ground line
2(0.6)
4(1.2)
6(1.8)
8(2.4)
10(3.0)
10(3.0)
Distance in feet (meters)

Figure [illegible]. Temperature profile of wood chip pile on 6-1-83.



Air temperature = +20°C
Top of chip pile
0°C
+20°C
+10°C
N ← → S
+ Temperature
⊕ Temperature and mesh bag
M Moisture probe
Distance in feet (meters)
20(6·1)
18(5·5)
16(4·9)
12(3·7)
8(2·4)
4(1·2)
Ground line
2(0·6)
4(1·2)
6(1·8)
8(2·4)
10(3·0)
10(3·0)
Distance in feet (meters)

Figure . Temperature profile of wood chip pile on 6-27-83.

Air temperature = +26°C

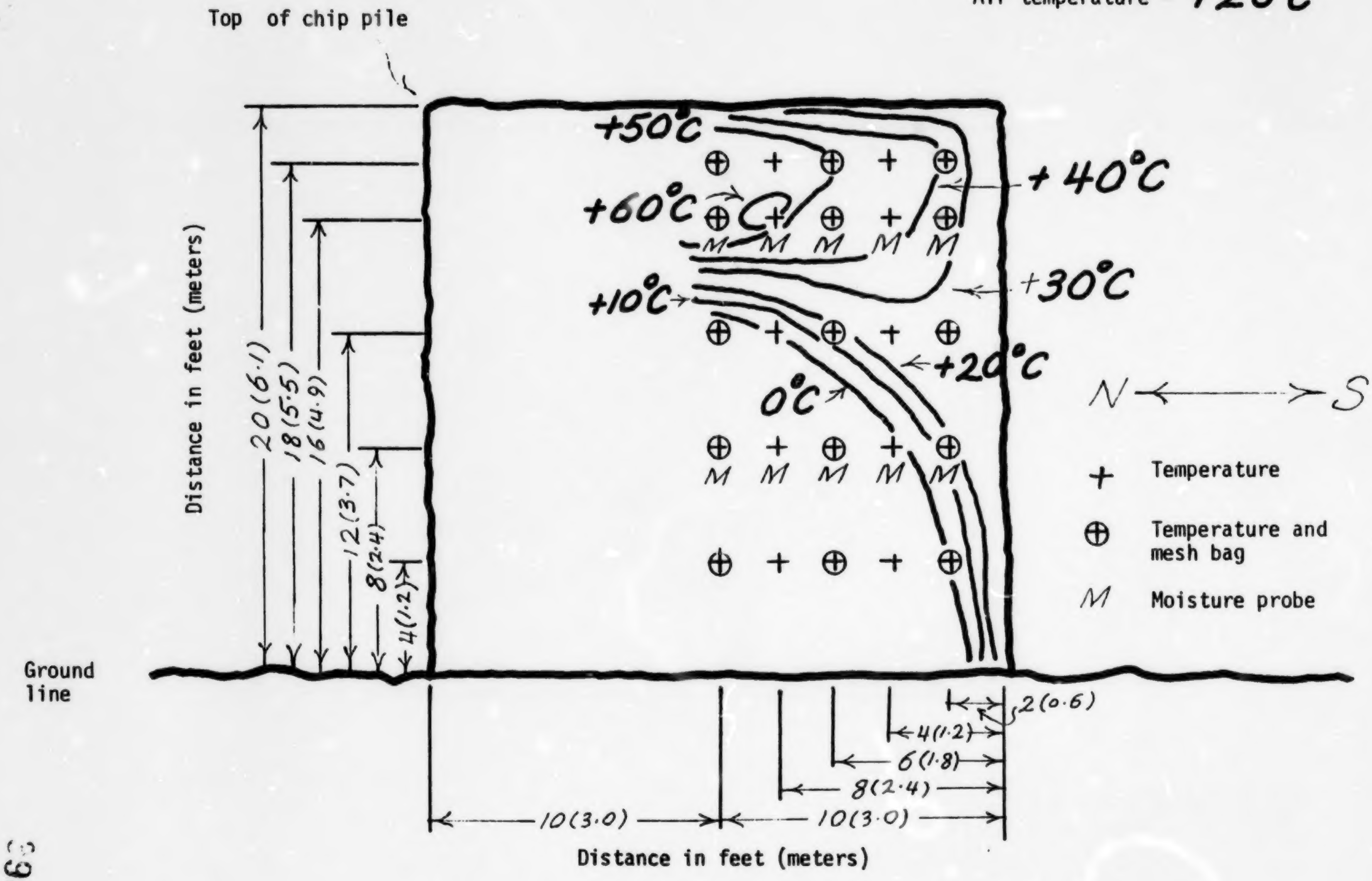
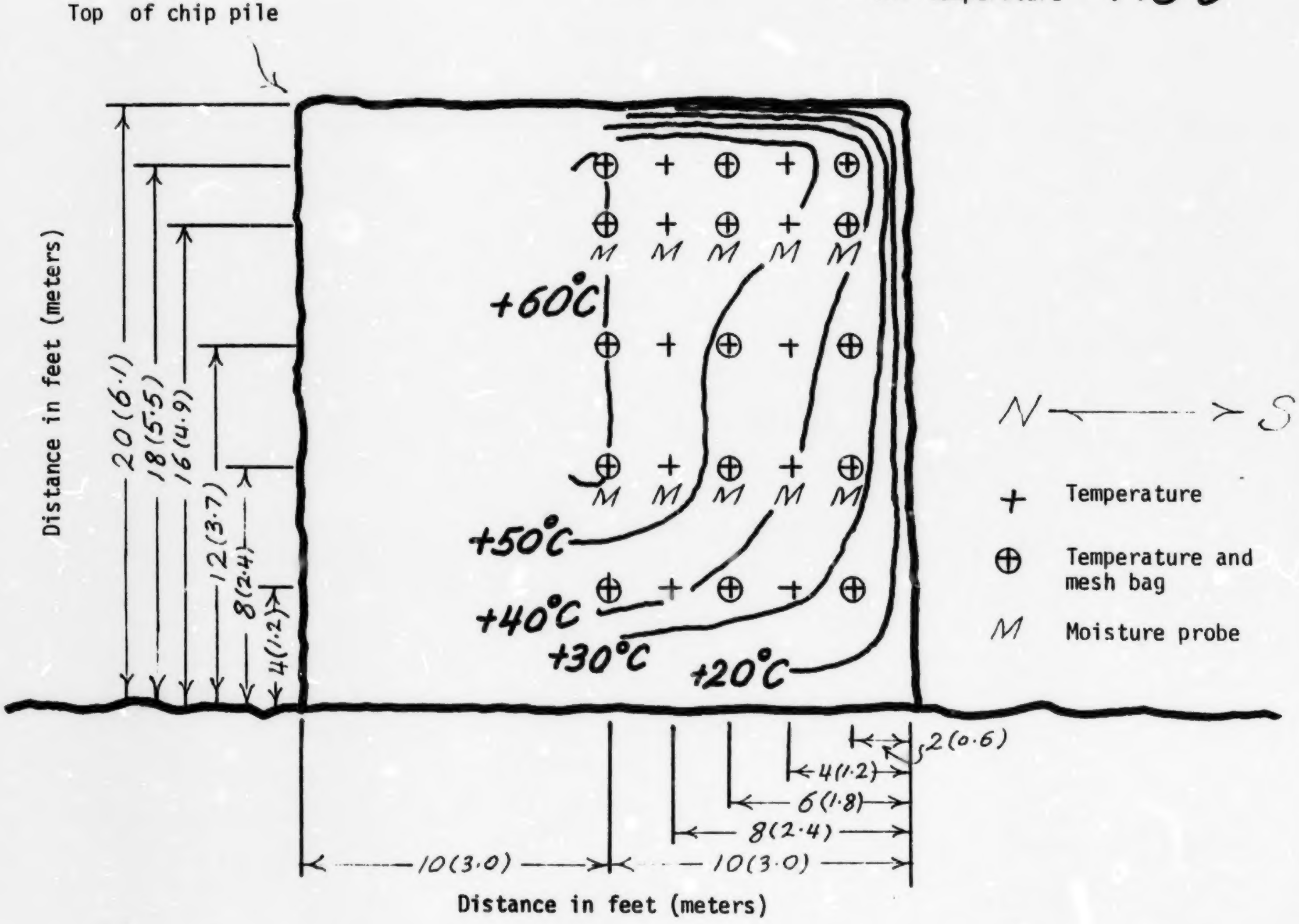

Top of chip pile
+50°C
+60°C
+40°C
+30°C
+10°C
+20°C
0°C
N ← → S
+ Temperature
⊕ Temperature and mesh bag
M Moisture probe
Distance in feet (meters)
20(6·1)
18(5·5)
16(4·9)
12(3·7)
8(2·4)
4(1·2)
Ground line
2(0·6)
4(1·2)
6(1·8)
8(2·4)
10(3·0)
10(3·0)
Distance in feet (meters)

Figure [illegible] . Temperature profile of wood chip pile on 8-12-83.

Air temperature = +15°C


Top of chip pile
Distance in feet (meters)
20(6·1)
18(5·5)
16(4·9)
12(3·7)
8(2·4)
4(1·2)
Ground line
+60°C
+50°C
+40°C
+30°C
+20°C
M
2(0·6)
4(1·2)
6(1·8)
8(2·4)
10(3·0)
10(3·0)
Distance in feet (meters)
N ——→ S
+ Temperature
⊕ Temperature and mesh bag
M Moisture probe

Woodchip Fuel Potential in Newfoundland and Labrador to Replace Oil in Existing Boilers and Furnaces

Philip M. Graham
Department of Mines and Energy
St. John's, Newfoundland

Abstract

The maximum potential on the island of Newfoundland for medium and small scale woodchip burning for building and process heat in boilers less than 5 MW capacity is approximately 150,000 green tonnes per year. The potential demand includes 90 existing boiler plants with oil consumption greater than 90 cubic metres per year (20,000 gallons per year considered medium scale) and 200 boilers and furnaces with an oil consumption of 23 - 90 cubic metres per year (5,000 - 20,000 gallons per year considered small scale). Beyond these limits there is the large scale industrial woodchip burning potential of approximately 110,000 green tonnes per year in existing boilers and kilns at three paper mills and a cement manufacturer. There is also some limited potential for residential scale chipburning.

Wood supply from sources without conflict with existing wood use is conservatively estimated to be 38,000 green tonnes per year sawmill residue, 160,000 green tonnes per year standing dead or junk timber and 980,000 green tonnes per year logging residue.

Two projects to be discussed (funded by Canada/Newfoundland CREDA) which illustrate the factors involved with woodchip supply and use are the Gander hospital wood boiler project and the small scale woodchip heating project.

WOODCHIP FUEL POTENTIAL IN NEWFOUNDLAND AND LABRADOR TO REPLACE OIL IN EXISTING BOILERS AND FURNACES

by Philip M. Graham, P. Eng.
Newfoundland Department of Mines and Energy

SUMMARY

Potential woodchip fuel demand to replace oil in existing boilers and furnaces is estimated to be 245,000 green tonnes per year by 1990 with government support. This would represent approximately 6% of the total provincial forest industry. Present woodchip fuel use is approximately 40,000 green tonnes per year at the Abitibi-Price and Bowater paper mills (bark excluded) and the Gander Hospital (23,000, 13,000 and 4,000 tonnes/yr. respectively). Potential demand is estimated to be 205,000 green tonnes/year. Derivation of this figure is the subject of this paper.

Table 1 shows potential wood fuel demand in relation to the 1979 Newfoundland Forest Industry Statistics.

Table 1

Activity	Production 000 green tonnes/yr	Value 000,000$	Percent of Total Production %
1979 Pulpwood	2,870	256	76
1979 Sawlog	370	11	10
1979 Roundwood Fuel	310	9	8
Potential Woodchip Fuel	245	7	6

SCOPE

This preliminary analysis is limited to the replacement of oil in existing buildings since this market is stable and combustion systems are commercially available at reasonable prices. Longer term potential not analysed here would include electrical power generation by both community scale wood gas engines (300 kW size range) or large wood-fired steam turbines (30 MW size range).

A variation on woodchips also not considered would be the use of wood pellets or briquettes in existing heating plants. Availability of densified wood would change the findings of this analysis in two ways: 1) regions such as the Burin and Avalon Peninsulas with insufficient fuelwood supply, could be included in potential demand if they were within the economical trucking distance of densified wood fuel produced on the Bonavista Peninsula and 2) the capital cost of densified wood handling and burning equipment would be less than the cost of woodchip equipment and the ecomomic attractiveness better.

APPROACH

The approach taken to estimate potential wood fuel demand (Table 2) was to identify potential users in areas with an adequate wood supply. For each potential user, the cost of a new wood boiler or furnace was estimated as well as the annual fuel saving from burning wood, (conservatively

TABLE (2)

PRELIMINARY ANALYSIS OF NEW WOODCHIP BOILERS OR FURNACES IN NEWFOUNDLAND AND LABRADOR TO REPLACE EXISTING OIL BURNERS

DEMAND CENTER		POTENTIAL NUMBER USERS	AVERAGE BOILER SIZE MW	CAPITAL COST WOOD BURNERS 000,000$	WOOD DEMAND 000 GREEN TONNES/YR	ANNUAL FUEL SAVINGS @ $15/ GREEN TONNE/YR 000$	AVERAGE SIMPLE PAYBACK YEARS	CAPITAL COST USED FUELSUPPLY EQUIPMENT 000$
CLARENVILLE	L	2	4.4	1.4	23	345	4	200
	M	3	0.6	0.5	3	45	11	
	S	20	0.3	0.6	4	60	10	
GANDER	L	1	3.0	0.7	10	150	5	100
	M	2	1.3	0.5	3	45	11	
	S	20	0.3	0.6	4	60	10	
GRAND FALLS	L	1	100	N/A	20	300	0	
	M	5	1.4	1.3	8	120	11	
	S	40	0.3	1.2	10	150	8	
BAIE VERTE	L	1	kiln	0.5	20	300	2	200
	M	4	1.4	1.3	7	105	12	
	S	25	0.3	0.8	5	75	11	
CORNER BROOK	L	2	kiln & 3.7	1.4	33	495	3	400
	M	2	2.1	0.8	3	45	18	
	S	50	0.3	1.5	15	225	7	
STEPHENVILLE	L	1	100	0.3	20	300	1	400
	M	4	0.7	0.7	4	60	12	
	S	30	0.3	0.9	8	120	8	
HAPPY VALLEY	L	-	-	-	-	-	-	
-GOOSE BAY	M	-	-	-	-	-	-	
LABRADOR	S	25	0.3	0.8	5	75	11	30
TOTALS		238		15.8	205	3075	5	1,830

estimated to be $15/green tonne/yr., $40 to purchase and burn one tonne of wood with an oil equivalent value of $55) allowing calculation of average simple payback. The capital cost of used fuel supply equipment is also shown.

Large scale (L) is defined as having a potential wood fuel demand greater than 10,000 green tonnes/yr., medium scale (M) would be 500 to 10,000 green tonnes/yr. and small scale (S) would be less than 500 green tonnes/yr. One green tonne wood is taken to be equivalent to 195 L oil (43 gal).

FINDINGS

The analysis shows 238 potential users with a total potential demand of 205,000 green tonnes/year.

Each of the island's six demand centers has at least one large scale user. Woodchip supply infrastructure to service the large user would be a prerequisite for much of medium and small scale use shown. Labrador would have to use a small scale woodchip production system since there is no large user.

Eight large scale users (paper mills, kilns and hospital) account for 60% of the potential demand (126,000 green tonnes/yr). These show good 3 year average paybacks since steam, hot water and hot gases are required year round.

Twenty medium scale users (commercial and institutional buildings) account for 15% of potential demand (28,000 green tonnes/yr). These show poor 11 year average paybacks due to the high cost of wood boiler capacity ($160,000 for 600 kW system) not offset by sufficient fuel savings since building heat in winter is the only load.

Two hundred and ten small scale users are estimated acounting for 25% of potential demand (51,000 green tonnes/yr). Paybacks average 9 years using containerized 300kW systems costing $30,000.

COMMENTS ON FUELWOOD SUPPLY

Wood fuel supply from sources without conflict with existing wood use has recently been surveyed by Newfoundland Forest Resources and Lands indicating the following total available wood from the island:

1.	Sawmill residue	30,000 green tonnes/yr
2.	Standing dead or junk timber	140,000 green tonnes/yr
3.	Logging residues	830,000 green tonnes/yr

Cost of fuel from these three sources is approximately $20/green tonne or less for mill waste, $20-$40/green tonne for whole tree chips and $30-$50 per tonne for logging residue. Areas close to the paper mills would likely have to obtain their fuel supply from logging residues from the pulpwood cutovers. This would necessitate a change in logging practice by the companies to concentrate the slash either on the cutovers for terrain chipping or at the roadside using whole tree harvesting methods.

In the analysis, three systems of wood supply are assumed: 1) the small scale production system for Labrador includes only a trailer mounted chipper and engine costing $30,000 for chipping wood obtained by the users, 2) for medium scale production, 10,000 green tonnes/yr, existing forestry equipment is assumed to be used with the addition of a new chipper and skidder valued at $100,000, and 3) a large scale production system of 20,000 green tonnes/yr would include two small feller bunchers ($160,000), one grapple skidder ($90,000) and one chipper (such as the Morbark 20, $170,000) for a total cost of about $400,000.

EMPLOYMENT

The employment which would result from woodchip use would be directly related to the annual demand. Based on the 3 woodchip supply operations presently in place in the province, one permanent job is estimated for each 1,000 green tonnes/yr of wood fuel. These jobs are for wood supply and boiler operation in the approximate ratio of 5:1. In addition to permanent jobs, one temporary person year for construction is assumed for each 1000 green tonnes of wood.

RECOMMENDATIONS

The recommendations of the Newfoundland Department of Mines and Energy for development of a woodchip fuel industry in the province would include the following:

1) discussion with potential large scale woodchip users to inform them and gauge their interest,

2) discussion with Bowater and Abitibi-Price on fuelwood from their limits,

3) formulation of a fuelwood policy by the Department of Forest Resources and Lands,

4) detailed study of woodchip fuel availability, supply and combustion where promising,

5) government incentives to promote the implementation of wood harvesting and burning where feasible, beginning with support of wood energy infrastructure demonstration project for Clarenville region involving capital cost assistance for one large user.

From Forest to Farm

George M. Barton
Wood and Bark Folige Chemist
Lion's Bay
British Columbia

Abstract

Following a brief review of the use of tree foliage in the Soviet Union as a poultry and animal feedstuff, studies involving Canadian species such as black spruce (Picea mariana), lodgepole pine (Pinus contorta) and white spruce (Picea glauca) will be discussed in detail. These studies will make special reference to chemical composition, separation techniques, poultry and animal feeding experiments and economics. In view of the similar chemical composition among the foliage of conifers, these studies should relate to Northern species.

From Forest to Farm

by G.M. Barton

September 30, 1983

Introduction

Thank you for inviting me here today to discuss the topic of "From Forest to Farm." Let me begin by stating that there is nothing new about the concept of animals eating foliage. From the beginning of evolution when animals and trees were first together on the earth, browsing of foliage was a fact of life. Naturalists are well aware of deer and moose enjoying a forest salad made up of leaves and needles. It must be noted, however, that given an ample supply of grass, clover or tender ferns, foliage was not their first choice. There are several good chemical reasons for this which will be discussed in detail later in this paper.

Interest in foliage utilization was at an all time high about eight years ago when there was a worldwide food shortage. In a 1975 article in the financial post (1) it was pointed out that the world's reserve supply of food was only expected to be 21 days compared with 89 days in 1969. Obviously then, if any part of the food chain normally fed to cattle, pigs or poultry could be replaced with foliage, land would be released to grow food for human beings. Other reasons given were the new complete tree harvesting concepts to improve the yields of lumber and pulp which, if implemented, would result in large amounts of foliage in central locations. Finally, there had been heavy pressure in many areas of Canada to reduce air polution from slash burning of branches and foliage. Thus, it appeared industry would be faced with the problem of what to do with vast amounts of foliage. In spite of the logic of these arguments the situation today is quite different. Newspaper headlines point out farmers are being asked to grow less not more food because of a world glut. Complete tree harvesting is still mainly in the future and slash burning is being advocated as the best way to control tree destroying insects and diseases. Today only the Soviet Union is commercially exploiting foliage for animal fodder.

Foliage Research in the Soviet Union

For nearly thirty years the Russians have been converting foliage from both coniferous and deciduous trees into marketable products. These products include the use of foliage as a vitamin supplement in animal feeds and a variety of foliage-derived chemicals in medicine, the cosmetics industry and veterinarian practices. This year they are expecting to produce 183,000 metric tonnes from 400 installations spread throughout Russia. Much of the research on foliage has been done under the direction of I.K Ievins at the Latvian scientific institute of forest problems in Riga. Another centre of Soviet research is in Leningrad under the direction of F.T. Solodkii. This work has been extensively reviewed (2,3,4) but for the purposes of this paper only research results relating to a fodder vitamin supplement will be cited.

In order to understand some of these results certain definitions are required. In the purest sense foliage refers only to needles or leaves. However, anyone who tries to collect foliage from a logging operation soon realizes there is also a lot of branch and twig material present. Unfortunately the inclusion of branch and twig material tends to detract from the nutritional value of the foliage for reasons soon to be discussed. Accordingly, the Russians decided on a definition of "Commercial or Technical Foliage" to be all leaves, needles, twigs, shoots and branches up to 0.6 cm (0.24 in.) in diameter. This then is the basic raw material they collect and process into a finely ground product called "muka." Muka is the Russian word for flour. Fodder made from coniferous trees is referred to as coniferous muka and from deciduous trees as deciduous muka. Muka from a pure species would be spruce muka, birch muka etc.

Russian claims for muka are impressive (table 1). It must be emphasized, however, that these claims are based on unknown Soviet control diets. Attempts to duplicate these results by Canada agriculture (5) or the university of B.C., animal science department (6) using Canadian species and North American control diets have not been successful.

Foliage Constituents and Their Role in Nutrition

Based on Russian analytical data, table 2 provides a comparison between muka and traditional fodder such as alfalfa. Although cellulose does provide energy for ruminants, since they are able to break it down to simple sugars, the percentages are meaningless without considering lignin contents. The reason for this is that lignin interferes with the accessibility of Rumen enzymes. Thus, while spruce has the higher cellulose content it also has a higher and more complex lignin that either birch of alfalfa. In addition, the more branch material included in the muka preparation the more lignin it would contain. In general wood contains up to 30% lignin whereas pure needles average 15 to 18%. In comparison alfalfa contains only 8 to 10% lignin. Thus animals instinctively eat grasses or plants containing the least amount of lignin. Higher lignin containing trees are eaten only as a last resort.

Although coniferous foliage contains 7 to 8% protein, some deciduous species such as poplar hybrids, average 19% on a moisture-free basis. This compares favourably with traditional fodder such as alfalfa at 18% and suggests that poplar leaves could be a source of protein for animals and even humans. A compensation for the lower protein coniferous foliage is that it can be harvested under winter conditions when alfalfa is not available.

More than half of crude foliage protein consists of simple proteins with albumins and glutelins predominating. A Russian study involving pines identifies 19 essential amino acids, the limiting ones being tryptophan and methionine. Lysine as well as methionine were identified as limiting amino acids in some experiments involving spruce and pine needles at agriculture Canada, Agassiz. B.C.

The fat content of foliage compares favourabgly with alfalfa and consists mainly of triglycerides and sterols esterified with fatty acids ranging in chain length from C12 to C24 units.

Ash content reflects the wide variety of minerals present in foliage. Table 2 recognizes some of the more important ones from a nutritional point of view. It must be noted, however, that the concentration of these inorganics is site dependent in the majority of cases. Thus trees growing in soils rich in manganese will impart a high concentration of this element to its foliage. One exception to this was noted in a study of lodgepole pine and white spruce growing in the same area of British Columbia. In this case the calcium content of the white spruce was found to be nearly three times greater than in the lodgepole pine foliage.

Carotene is related to vitamin A as can be seen from figure 1. Although ruminants can easily convert carotene to vitamin A during their digestive process, this vitamin is usually given by injection in North America. Vitamin A is made synthetically and so the cost of administering this vitamin is very inexpensive. However, the measurement of carotene in foliage is important for another reason, namely, as an indicator of foliage freshness. As might be expected from its chemical structure carotene can be easily oxidized. Canadian studies (7) have shown that although loss of carotene soon occurs after foliage has been cut, felled trees retain a significant amount of this substance during a two month period under winter conditions compared to a one month period under summer conditions. This difference is due to temperature and sunlight. Although not noted in table 2, the oxy carotenoids (Xanthophylis) closely related chemically to carotene, are important in the pigmentation of chicken eggs and impart the fresh, yellow color to chicken flesh. Traditionally, these pigments have come from yellow corn meal, marigolds and alfalfa, but studies have shown (8) they can be adequately provided from lodgepole pine needles.

Also missing from the Russian data in table 2 are essential oils. All conifers have their own distinctive smell. The term essential is derived from a traditional belief that the fragrance of a substance contained the very essence of it, i.e., the vitally important ingredient. These essential oils usually have a pleasant scent and some are highly prized as perfume ingredients. While essential oils cannot be considered nutrients, they can exert a negative response in animals being fed foliage. Chickens, for example, will selectively pick out and discard foliage unless the rations are pelletized. Of greater concern was the possibility that the meat from animals eating foliage would be tainted by the essential oils. Fortunately, within the limits of studies completed in Canada (5,6,9) coniferous muka did not impart any detectable flavour to the meat of chickens or sheep.

Foliage Research in Canada in the 70's

Foliage research in Canada was well advanced, both in the west, at the Western Forest Products Laboratory, Vancouver, B.C., the University of B.C., Animal Science Department and Canada Agriculture, research station, Agassiz, B.C. and in the east at Domtar research and development headquarters Senneville, Quebec. In the west the main emphasis was on lodgepole pine (pinus contorta) and white spruce (Picea glauca) foliage. These trees were chosen because they, or closely related trees, are well represented commercially throughout Canada and because whole tree logging was more likely to be practiced first on these trees than on mountainous or coastal tree species. The Domtar studies emphasized black spruce (Picea mariana) for similar reasons. Although detailed discussion of these studies is beyond the scope of this paper, the following conclusions clearly show that while Canadian coniferous foliage can compete with hay on a nutritional level it is not presently a viable alternative to conventional feedstuffs because of adverse economics.

General Conclusions on Canadian Studies Involving Muka from Black Spruce (Picea Mariana), Lodgepole Pine (Pinus Contorta) & White Spruce (Picea Glauca)

(1) Seasonal variations in the organic constituents of foliage affect mainly the amounts of essential oils and carotene with higher values being present during the winter, protein and chlorophyll amounts remain relatively constant throughout the year.

(2) Inorganic constituents are mainly site dependent, however it was found that spruce foliage contained nearly three times the calcium content of pine.

(3) Felled trees retain a significant amount of their foliage nutrients during a two month period between harvesting and processing under winter conditions compared to a one month period under summer conditions.

(4) Within the limits of the reported experiments, muka preparations had no adverse effects on the mortality of diseases of chickens, rats or sheep.

(5) In the same context, muka preparations did not impart any detectable flavour to the meat from chickens or sheep.

(6) Contrary to the Russian results, the inclusion of muka in North American control diets up to the 10% level did not improve the growth rates in chickens rats or sheep.

(7) The nutritional value of muka prepared from these species must be compared to a low to medium grade hay.

Specific Conclusions on the Black Spruce Study Prepared for the Canadian Government by Domtar Inc. (DSS File No. 06SZ. KL 210-7-5022)

(1) Mechanized harvesting, together with transportation of whole trees to the mill and a central delimbing and slash-chipping facility results in a reduced wood harvesting cost and a supply of chipped green slash at the mill site at no cost. At Quevillon, Quebec, mechanized harvesting methods could reduce wood cost by $800,000 to $2 million annually giving a 11 to 25% DCF return on investment in the harvesting equipment, while at the same time providing 250,000 tons of green chipped slash.

(2) The chipped green slash delivered to the mill is a valuable source of fuel and 213,000 TPY at a fuel value of $14.25/ton can save approximately 3 million dollars annually.

(3) Steaming of black spruce needles to remove the essential oils appears to have little effect on the nutritional value, and reduces the dry matter digestibility in artificial rumen tests.

(4) The cost of muka to the consumer would have to be $165/ton based on the production at Quevillon of 13,500 TPY of black spruce needle muka from 213,000 TPY of chipped green slash and a 12% DCF return on the muka plant investment. This cost is more than four times the nutritional value of muka to the customer.

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Table 1

Application and Benefit of Muka in Soviet Rations(1)

Type of Muka	Livestock	Approximate Recopmmended Dosage, %	Benefits derived from use
Conifer	Poultry	5	Reduced susceptibility to diseage; 18% increase in weight; increased egg production
Pine	Cattle	5	Reduced susceptibility to disease and sickness; increased vitality; 15 to 20% increase in weight; easier period of gestation
Spruce	Cattle	8	Same as above
Conifer	Milk cows	5	Healthier cows giving 12% additional milk
Conifer	Pigs	5	15% increase in weight; reduced susceptibility to sickness

Table 2
Partial Composition of Conifer and Hardwood Muka Compared to Alfalfa (2)
(Based on Russian Data)

	Spruce Muka	Birch Muka	Alfalfa
Cellulose %	35.6	18.0	26.2
Protein %	8.8	8.0	18.3
Fats %	6.5	8.2	3.2
Ash %	4.4	4.2	9.6
Carotene mg/kg	139	380	172
Calcium %	0.7	0.8	1.1
Phosphorous %	0.2	0.3	0.3
Potassium %	0.4	0.7	1.3
Magnesium %	0.6	0.3	0.2
Iron mg/kg	159	101	212
Manganese mg/kg	292	30	29
Copper mg/kg	6	8	10
Zinc mg/kg	32	121	16
Cobalt mg/kg	158	90	360

Additional Reading "From Forest to Farm"

Available from Forintek Canada Corp., 6620 N.W. Marine Drive, Vancouver, B.C. V6T 1X2 (please enclose a $2 charge for handling and mailing)

(1) Recent Advances in Foliage Utilization by J.L. Keays and G.M. Barton, Canadian Forestry Information Report VP-X-137, 1975 94 pages

(2) Foliage Part 1: Practical Utilization of Foliage. J.L. Keays, Applied Polymer Symposium No. 28:445-464, 1976

(3) Foliage Part II: Foliage Chemicals, Their Properties and Uses. G.M. Barton Applied Polymer Symposium No. 28:465-484, 1976

(4) A New Look at Foliage Chemically by; G.M. Barton and B.F. MacDonald Tappi 61(1):45-48, 1978

(5) Nutritive Value of Spruce Muka (Foliage) for the Growing Chick by J.R. Hunt and G.M. Barton Animal Feed Science and Technology #3,63-72, 1978

(6) Chemicals from trees, Outlook for the Future by G.M. Barton, Forintek Canada Corp, Technical Report No. 4,12 pages, 1979

(7) From Forest to Farm by J.R. Hunt and G.M. Barton Canada and Agriculture Fall Issue 2 pages, 1979

(8) Are the Forests a new Protein Source? by J.A. McIntosh and D.M. Wright B.C. Lumberman April 1977, 3 pages

Avilable from Agriculture Canada, c/o Dr. J.R. Hunt, Research Station P.O. Box 1000, Agassiz, B.C. V0M 1A0 (no charge)

(1) Utilization of Lodgepole Pine (Pinus Contorta) MUka (Foliage) by Sheep R.M. Tait, J.R. Hunt, C. Gaston and G.M. Barton Canada. Jour. Animal Sc. 62:467-71, 1982

(2) Evaluation of Conifer Foliage as a Pigmentation by J.R. Hunt, B.F. MacDonald, and G.M. Barton (abstract only)

Available from Domtar Inc. c/o Mr. H.D. Lightfoot, Research Centre, Senneville, Quebec, H9X 3L7 (available at cost approximately $25)

(1) Studies on Animal Feed Supplements from Canadian Tree Foliage DSS File No. 06SZ.KL 210-7-5022) 225 pages, 1978

Wood Gasification for Power Generation

Sieg Philipp
President, Snow Shoe Inn Inc.
Fort Providence, NWT

Dana Ferguson
Ferguson, Simek, Clark ltd.
Yellowknife, NWT

1.0 SYNOPSIS

This report was commissioned by CREDA to provide the results of the experience gained from the construction and operation of a wood gasification system for electrical power generation.

The option of substituting the normal diesel fuel with wood is an exciting and potentially economically attractive proposition. The owner of the Snowshoe Inn, Fort Providence, N.W.T. set out his requirements and commissioned a German firm to supply a wood gasification system. Eighteen months after the initial installation much has been learned about the potential of wood gasification for power generation.

Problems still exist, but it is hoped that through the rigorous testing of the manufacturers' claims, the results that have been achieved and documented can be used for assessing the viability of similar future projects.

2.0 PROJECT SUMMARY

Due to the very high energy costs, the owner of Snowshoe Industries was forced to make large savings in his heating and power expenses. The first step of generating his own power with diesel generators, and using the cooling water for heating, was completed in 1973. It was calculated that there could be further savings by using wood as a fuel source, rather than oil. Various types of wood gasifying plants were considered, with a German made downdraft wood gasifier eventually being chosen. A proposal was given to CREDA in 1980 and an amended version was accepted.

The gasifier has been installed for 18 months and during that time the owner has been tuning its performance with the aim of ultimately having continuous trouble-free operation. Many problem areas have come to light and this year B.C. Research was called to Fort Providence in order to analyze the system. This report documents the project from the initial stages to the present time and highlights the areas where others may benefit from the experience.

Acknowledgements

Mr. Sieg Phillip, who owns and manages the Snowshoe Inn, is responsible for instigating and working of this project through to the conclusions that have been reached at this stage. His time spent in helping to compile this report is appreciated.

3.0 PROJECT BACKGROUND

SNOWSHOE INN LIMITED, is a business started in Fort Providence in the N.W.T. in 1965, originally on a very small scale. Steady expansion and diversification over the following 6 years, encouraged by oil exploration in this area, made the business an economically viable but marginal operation.

In 1971/72, a financial forecast was made for a badly needed building program to replace outdated and inefficient mobile accommodation units. The conclusion of the forecast showed that bankruptcy was likely within one year, unless revenues could be increased or overhead decreased. Since it seemed very doubtful that revenues could be increased beyond the forecast, the two largest expense items electric energy and cost of heating were examined and anlayzed. Calculations indicated that a self-contained diesel-electric generating plant, installed as a total energy system, could decrease estimated energy costs by at least 50%, and pay for itself within four to five years.

The decision was made to go ahead with the expansion program as planned, but with the addition of a generating system owned and maintained by the Inn.

The installation of the "total energy system" was completed in November of 1973, and consisted of one 75 KW Diesel-electric generating set, and one 100 KW unit. (A 175 KW unit was added in 1978). Heat was recovered via an exhaust heat exchanger, in the form of hot water, and combined with the hot water from the cooling system of the unit on the line. This hot water was fed into an insulated, partially underground and partially above ground circulating system, linking and heating all of the buildings within the Inn grounds.

The 1,672 sq. m. (18,000 sq. ft.) motel under construction since May 1973 was completed by late 1974. Unlike the existing buildings, where heating systems had to be modified in order to use hot water, the new building was designed to be heated by recovered waste heat, plus some electric heat, to individually controlled thermostats in occupied rooms. Instead of having become a dangerous liability, the revised expansion program turned out to be the salvation of the company.

The energy crisis in the winter of 1973/74, although not affecting the Inn, at least made it realize that depending entirely on a non-renewable fossil fuel energy supply was foolish, if not dangerous. Over the following six years a number of alternate energy sources were researched, and for one reason or another discarded or shelved; biomass excepted. Poplar, jackpine and spruce of little or no commercial value, but growing in abundance in the Fort Providence area, became the alternate energy source that the Inn owner decided to explore.

Wood fired, steam turbine, power generation; (a proven way of generating electric energy with just about anything that burns) seemed the obvious choice, though research into this field showed that it would not be economically feasible to operate such a system on a small scale.

Gasifying wood into a clean combustible gas to fuel internal combustion engines was another means to be further explored. Wood gasification first developed in the 1920's and was used extensively during the second world war in Germany and Western Europe to operate cars, trucks, buses and even boats. It was found that some of the people involved in the development and manufacture of the original Imbert Downdraft Wood Gasifier (used almost exclusively during the war) were again manufacturing wood gasifiers for power generation in Germany.

Another manufacturer, Duvant in France was experimenting with, and building, similar downdraft gasifiers, but using the wood gas in fuel engine-generating systems only. A fuel ray ignition system in which 10-15% of full load engine fuel requirements are at all times supplied in form of Diesel fuel through an injection system, and only the fuel requirements over and above this amount is made up of wood gas.

After exploring the advantages and disadvantages of both systems it was felt that the Imbert principle of using wood gas only in spark ignition engines would be more advantageous, since it promised to eliminate dependency on diesel.

In April 1980, a proposal to purchase, install and operate a wood gasification-power generating plant as a demonstration project, was forwarded to the Renewable Energy Division of the Government of the Northwest Territories. (A copy of this proposal is included as an Appendix). A slightly revised version was eventually approved on a cost sharing basis, between Snowshoe Inn Ltd., the Government of the N.W.T. and the Department of Energy, Mines and Resources, Government of Canada.

The 120 KW generator with a Low BTU gas (wood gas) engine, complete gasification system and automatic fuel feed, ordered from Imbert Energy Technick in Germany, was to be ready for test running at their factory in Germany in December 1980. After a number of postponments, the first test run, with Mr. Phillip in attendance, took place on February 23, 1981. Although the plant seemed to be operating satisfactorily, several deficiencies became apparent,the major problem was the fuel feed system. Mr. Phillip had specified that it be fully automated, but it had been built as a semi-automatic system, requiring a full time operator to push buttons whenever the gasifier required more wood. The changes that had to be made were considerable, and took 3 weeks. The next and final factory test run, at which Mr. Phillip was present, as carried out on March 17.

The plant was put through its paces at varying load levels, right up to full load plus 10% overload. This initial performance was excellent, but it was found that whenever Mr. Phillip turned his back on the control panel to check up on one thing or another, the electric load was being lowered immediately to 60 or 70 KW. When finally questioned, the technician answered that he had been instructed to do that to conserve wood, as there was not very much on hand. At the time this appeared a reasonable explanation. Not until some months later was it discovered that the real reason was to prevent overheating of the engine, which had apparently been happening on high loads over extended periods of time. This was to be corrected by installing different pistons after the test run, but was never officially admitted to Mr. Phillip.

A number of minor deficiencies noted at the test run were to be corrected immediately. The plant was then to be dismantled, packed into a container and shipped from Bremerhaven the second week in April. Many phone calls overseas, and 8 weeks later, the plant was finally shipped - June 12, 1981, packed in a 46 cu. m. one way container. It arrived in Vancouver July 10, 1981. Except for a short delay caused by the tail end of a longshoremen's strike, the transport of the container via CNR flatcar from Vancouver to Edmonton and from there via Snowshoe Inn's own transport to Fort Providence posed no problems.

Although a 12.5 x 31.3 m (40' x 100') building as originally planned would have been large enough to accommodate the original pilot plant, Mr. Phillip decided to increase the size of the building to 21.9 x 45 m (70' x 144'), to facilitate future expansion of the gasification and generating plant without having to make any changes to the building.

The assembly and installation of the plant, as well as the tying in of the new generator into the Inn's grid, and the cooling and exhaust system of the new engine into the Inn's heat recovery plant, was carried out by Snowshoe Inn's staff under Mr. Phillip's supervision and was completed by mid-October.

A clause in the purchase contract with Imbert provided that a factory technician would have to inspect the completed installation and be present for the firing up, in order to be eligible for the warranty. A technician of Imbert was flown over for that purpose and the plant was fired up for the first time on October 16, 1981.

4.0 OPERATION OF GASIFIER AND FEEDING SYSTEM

Feeding System

One of the requirements of an automatic gasifier is the provision of an automatic wood feeding system. In this case, the building is large enough to allow wood chips to be stockpiled in dry conditions. To aid drying, the concrete floor slab is heated by the generator motor cooling water and exhaust gases. Another source for drying chips is the heat given up by the wood gas to the cooling tower water. This water is pumped to a fan-coil unit which blows warm air over the chips.
If the generator runs continuously, the day hopper requires approximately every 24 hours, depending on the connected electrical load over the particular period of time. The wood chips are moved from the day hopper to the gasifier automatically, via a conveyor, upon demand from a level control within the gasifier.

Gasifier

The Imbert wood gasifier is a downdraft suction plant operating with negative pressure throughout.

As a result, air enters through the tuyeres connecting the air intake chamber to the nozzles, located at equal distances around the hearth. Air is drawn through the nozzles into the hearth and the reduction zone of the gasifier, producing gas on demand. Any leaks in the system, allowing air to enter anywhere else but through the nozzles, is detrimental to the operation.

For initial start up of the gasifier, charcoal is filled inside and around the hearth to several inches above the air nozzles. The remainder of the gasifier is then filled with wood. To light the gasifier, a battery operated suction fan is switched on, creating a vacuum in the system, sucking air through the nozzles into the hearth of the gasifier. Some burning tissue or fine wood shavings, held into the air chamber, will be sucked through one or more of the nozzles into the hearth, instantly igniting the charcoal. The discharge pipe of the suction fan during this stage is connected via a rubber hose connection to a galvanized duct which is vented to the atmosphere.

The charcoal, once ignited, reacts very quickly with the in-rushing air in the gasification hearth, increasing the hearth temperature very quickly to between 1100 degrees C and 1400 degrees C.

The air rushing through the nozzles partially oxidizes the charcoal to carbon monoxide, a combustible gas, and partly into non-combustible carbon dioxide. By drawing these gases through the glowing charcoal bed, the carbon dioxide is reduced to carbon monoxide, thus increasing the combustible components of the gas. The heat released in the hearth during the process carbonizes the wood progressively within the loading chamber into charcoal. Thus, the gasifier continuously produces the charcoal to be gasified. The vapour and gas released in the process can only escape downward through the red hot charcoal bed, where the high temperature decomposes the vapour partly into hydrogen and oxygen. Even the phenols and tar are decomposed, cracked and transformed into combustible gases. The oxygen released from the vapour supports the gasification of the charcoal apart Carbon Monoxide and the methane released in small quantities. The hydrogen generated is a very important component of the generator gas.

The remaining ash has been, and should be, only 1% of input mass weight, but has been as high as 2% due to excessive grate drive operation, grinding some of the charcoal into ash. The gas leaving the gasifier, carries with it dust and fine ash particles. By routing the gas through cyclones, the large and medium sized ash particles are removed. After leaving the cyclones the gas enters the water cooling and cleaning tower, where most of the fine dust particles are removed by exposing the gas to a very heavy water spray. At the same time the gas is cooled from an initial 400 degrees C at the gasifier outlet to 35 degrees C when leaving the cooling and cleaning plant. A cork filter at the top of the cooling tower acts as a primary filter,into and through a secondary cork filter, and enters the base of the engine which acts as a small reservoir. From this reservoir, one pipe leads to the battery operated suction fan. Two 75mm pipes lead to the engine air mixing and throttle valves. Within 10 minutes of lighting the gasifier, the rubber hose connection, connecting the discharge of the suction fan to the vent, may be disconnected and the discharged gas ignited by means of a match or small torch. A flame approximately 1m long, blue with a red tinge, indicates that the gas is of good quality and the engine may be started. The gas could be flared and the engine started within 3 to 5 minutes after lighting the gasifier, but waiting the extra 5 minutes assures a better quality of gas. To start the engine, the battery operated suction fan is switched off, a valve between the suction side of the fan and the reservoir closed, the engine ignition turned on, the engine turned over by its electric starter and the air mixing valve slowly opened. The engine should start immediately. From here on, gas is produced by the suction of the engine, relative to its load.

As charcoal in the gasifier is gradually decomposed into gases and ash, the density of the charcoal bed, through which the gases have to pass, slowly increases. This causes the low pressue on the engine side of the charcoal bed to increase. When the low pressure at the gas outlet port of the gasifier increases to 1.75 kPa (7" of water column) a pressure switch provided at that point, causes the grate drive motor to be actuated, revolving the grate below the charcoal bed, causing the accumulated ash to fall through the grate into the ash container. Removing the restriction in the gas flow drops the low pressure back to 0.88 kPa (3 1/2" W/G) at which point the grate drive is switched off. A vibrator mounted to the outside of the gasifier has been found to be of considerable help in keeping the charcoal bed free of ash for longer periods, requiring less grate drive operation, and decreasing the incidence of bridging of wood in the gasifier.

A feed control in the upper part of the gasifier determines when wood needs to be added.

Upon a signal from the feed control to the control panel, the automatic feed cycle is put in motion by closing the sliding door between the gasifier and the airlock. As soon as the slider is closed, the outer airlock door opens and when fully open, the conveyor runs for thirty seconds, controlled by an adjustable timer. During this time, between 8.2 kg. and 10 kg. of wood chips, (12.7 to 13 kg. of saw cut wood, is deposited into the airlock of the gasifier. When the conveyor stops, the outer door closes and the lower sliding door opens, allowing the wood to fall into the gasifier. This feed cycle will be repeated until the feed control cancels the feed signal indicating that the gasifier is full.

5.0 GASIFIER SYSTEM PERFORMANCE

Although initial problems were anticipated, the seemingly very satisfactory test run in Germany had not prepared Mr. Phillip for the number of problems that in fact occurred. Nor was it realized how seriously apparently minor problems could affect the reliability of the system, and how difficult they would be to correct. Details of those problems, and their solutions are described in the following table. Imbert Energy Technick was made aware of some of the major problems, promised to study same, and advise possible solutions.

Poorly designed and badly manufactured throttle valves, resulting in unsatisfactory engine operation, were to be replaced on warranty, by a new, larger diameter and better designed valve, twelve months ago. To date, the replacement parts have not been received.

One of the major obstacles to making wood gasification a realiable alternate fuel for electric power generation has been bridging of the wood chips, the gasifier or feed system. During the overseas test run, Imbert used scraps from furniture manufacture, which is mostly saw cut pieces of hardwood, of irregular shape and size. In Fort Providence, chips are produced by a chipper from fire killed, very dry Jack Pine, with a much greater tendency to interlock and bridge. The difference in heat value of hardwood compared to jack pine is negligible on a mass basis,but significant on a volume basis. Due to a much lower mass by volume of the wood that is being used, the feed rate of fthe wood to the gasifier for a given load increases, compounding the problem of bridging, and allowing more air to enter the gasifier, due to the increased number of feeding cycles.

This causes a lowering of the heat value of the gas during that period. Techwest Enterprises Ltd. of Vancouver, B.C., under sponsorship of Energy, Mines and Resources, with Mr. David Fung of Canmet the Scientific Authority, sent a team of researchers to Fort Providence to analyze the gas produced under actual operating conditions, and help identify the causes of engine stalls.

The results of these tests have helped considerably. A copy of the Techwest report is included as an Appendix. Information on the effectiveness of a different automatic wood feeding system under development by Imbert was requested more than twelve months ago, but to date no information has been received. This system, using a different principle to introduce the wood into the gasifier, could be adapted to this gasifier. Such an arrangement could increase the reliability of the plant, since it would eliminate bridging of the wood to a large extent, and would not allow false air to enter the gasification process.

The following table outlines the problems that have occurred from the outset of the gasifier operation, together with the resulting modifications and some solutions.

TABLE 1 - PROBLEMS INCURRED DURING GASIFIER OPERATION

Problem	Cause	Modifications	Final Solution	Comments
1. Bridging of wood chips within air-lock	Unsuitable timer on conveyor. Adjustment did not allow as short a time of operation as required.	1. Made a vertical cylinder same size as cover to bypass gasifier slanted walls. Bridging still occurred. 2. Installed a vibrator in a variety of positions. No effect.	Substituted conveyor timer with one having adjustment down to zero time. Timer set at 30 seconds which proved to be the longest allowable time period of filling before bridging occurred.	A side-effect of shortening the time for filling is that more air is now allowed into the gasifier, due to the higher number of smaller feeds.
2. Original Level sensor malfunctioned.	The electronic sensor became coated with carbon which made it inoperable.		Sensor substituted with a "bin-dicator" paddle sensor. This sensor, commonly used in grain silos, consists of a continuously rotating paddle which stops turning when the wood chip pile makes contact with the paddle. A signal is then sent to the control panel.	
3. Bridging in day hopper.	Manufacturer installed vibrator was unsatisfactory		Hopper outlet was redesigned and fabricated to streamline the wood chip path on to the conveyor.	The vibrator is still required to operate.

Problem	Cause	Modifications	Final Solution	Comments
4. Tarring of butterflies within gas mixing valves, resulting in difficult governor operation.	. Residual carbon particles in the woodgas, condensed on to the valves as cool air is drawn into the gas flow.	. Intake air is now preheated to a higher temperature than that of the product gas.	. The permanent solution may be to install an electrostatic filter.	.
5. Large difference in generator motor exhaust gas temperatures from each set of manifolds.	. Poorly designed and manufactured trottle valves, allowing varying quantities of gas to enter the separate manifolds.	. 1. Re-engineered the valves. 2. Manufactured a common chamber after the valves, from which the motor intake manifolds are connected.	. The ideal solution would be to have: : one gas pipe from which the two intake manifolds are connected. : one mixing valve : one throttle valve	.
6. Leaking welds in two of the air supply pipes from the inlet chamber to the nozzles.	. Poor welding.	.	. Rewelded pipes.	.
7. Backfiring in gasifier	. Air leaking into the gasifier, combining with the combustible gases and exploding. See Problem 1.	.	.	. Safety devices are built into the gasifier system. 1. Spring-load cover. 2. Covers at ends of slider valve. 3. Cap on top of gasifier cover. 4. Cap on top of first cyclone.

Problem	Cause	Modifications	Final Solution	Comments
8. Backfiring in generator motor.	. Too lean mixture. Combustion too slow and still occurring when inlet valves open. The result is an explosion in intake manifold.	.	.	. A side effect of Problem 1.
9. Air leaks through asbestos gasket on flanges either side of gasifier combustion zone.	. Asbestos does not give good seal. Also high temp. range of gasifier, with resulting expanding and contracting, creates gaps at flanges.	.	. Flange bolts must be tightened periodically.	.
10. Air leakage past asbestos graphite seal around gasifier cover.	. Incorrect seal for application.	.	. Replaced seal with high temperature silicone.	.
11. Excessive quantity of charcoal falling into ash container.	. Poorly manufactured and fitted grate.	.	. Ash container removed and grate drive modified to give a closer fit to gasifier casing.	.
12. Slider valve inoperative.	. Broken gear.	.	. Build new gear.	.

FINANCIAL ANALYSIS

The Wood Gasification Proposal, included as an appendix of this report, gives a detailed breakdown of the heat values of wood compared to that of diesel fuel and the resulting financial comparisons for the separate systems.

During the period April 27-28, 1983, a team from B.C. Research was sent to Fort Providence to collect data on the gasifier system and assess its performance. During that time, data was also collected regarding the efficiency of the gasifier system and it was determined how much of the energy stored in the wood could be reused.

The following data were collected during the test run.

Total number of hours of operation	= 8.5 hours
Total KWH produced	= 550 KWH
Wood consumed - block	= 129 kg. (284 lb.)
- chips	= 340 kg. (749 lb.)
Total	= 469 kg. (1,033 lb.)

The above wood consumption figures are based on:

Blocks: 10 feedings at 5 conveyor pockets per feeding and 2.575 kg. (5.67 lb.) per pocket.

Chips: 41 feedings at 5 conveyor pockets per feeding and 1.66 kg. (3.66 lb.) per pocket.

During the above test run, the heat that was recovered was monitored on the BTU meters incorporated into the system. The data obtained produced the following figures:

Heat recovered from gas cooler (which is reused to dry the wood chips waiting to be loaded onto the hopper) = 140 KWH

Heat recovered from engine cooling water (which is reused to provide heating for the Snowshoe Inn) = 390 KWH

Breakdown of Energy Output from the Gasified Wood

Using a combination of values obtained from scientific research and those obtained during the test run, the following data was noted. (Note: the data is documented first in metric and then in imperial).

468 kg. of Jack Pine @ 1.88 KWH per kg. has a total energy capacity of 1,936 KWH.

The energy output from the test run was:

1. Electrical Energy : 550 KWH (28.5%)

2. Heat Energy from Generator Motor Cooling Water : 390 KWH (20.0%)

3. Heat Energy from Cooling of Wood Gas : 140 KWH (7.2%)

:1080 KWH (55.7%)

The following should be considered as additional energy that can be extracted.

4. Only 75% of the motor's cooling water could be used, because the Inn's heating system did not require the total heat. The excess 25% had to be bypassed, but there is potentially another 6% that can be used. :
: 116 KWH (6%)

5. Due to the fact that the exhaust boiler was undergoing it's annual maintenance, none of the heat contained in the generator motor exhaust could be recovered. However, of the 674 KW in the exhaust gas, approximately 440 KW can be recovered.
So there is a potential of : 440 KWH (23%)

Of the original 1936 KWH of energy stored within the wood, 84.7% of the energy could be used.

Summary of Test Results in Imperial Units

Total wood used in the test, 1013.8 lbs. of Jack Pine @ 6405 Btu per lb., has a total energy capacity of 6,608,679 Btu.

The energy output of the test run was:

1. Electrical Energy :1,877,150 Btu (28.5%)

2. Heat Energy from Generator Motor Cooling Water :1,331,070 Btu (20.0%)

3. Heat Energy from Cooling of Wood Gas : 447,820 Btu (7.2%)

4. Additional Energy from Generator Motor Cooling Water, Not Used in the Test : 395,904 Btu (6.0%)

5. Potential Energy From Generator Motor Exhaust, Not Used in the Test :1,500,000 Btu (23.0%)

Total 84.7%)

Updated Financial Analysis of Gasification System

Now that the system has been operating intermittently for 18 months, the economics of running such an operation as follows:

Fuel Cost

Diesel Fuel: 167,293 litres @ $0.363/litre = $60,720
(36,800 gallons @ $1.65/gallon

Wood: 562 cords @ $55.00/cord = $30,910

Annual Savings from using wood fuel = $29,810

Wages

It has now become clear that the gasifier cannot operate without full-time supervision, 24 hours per day. Not only must we consider the problem of getting reliable staff for the shift work, but the additional cost is a heavy burden.

Wages @ 24 hours @ $8/hour = $ 70,080
So the annual cost of operating the gasifer = $100,990

The fact that the wood gasifier requires full time supervision makes its choice, over the diesel fuel generator, an economically unattractive one.

7.0 CONCLUSIONS

It is always hoped that the conclusions for a particular project clearly indicate its success or otherwise. Initially it was hoped that these conclusions would include a recommendation that a wood gasification system, used as a source of electrical power, could be an attractive alternative to the standard diesel fuel power generation.

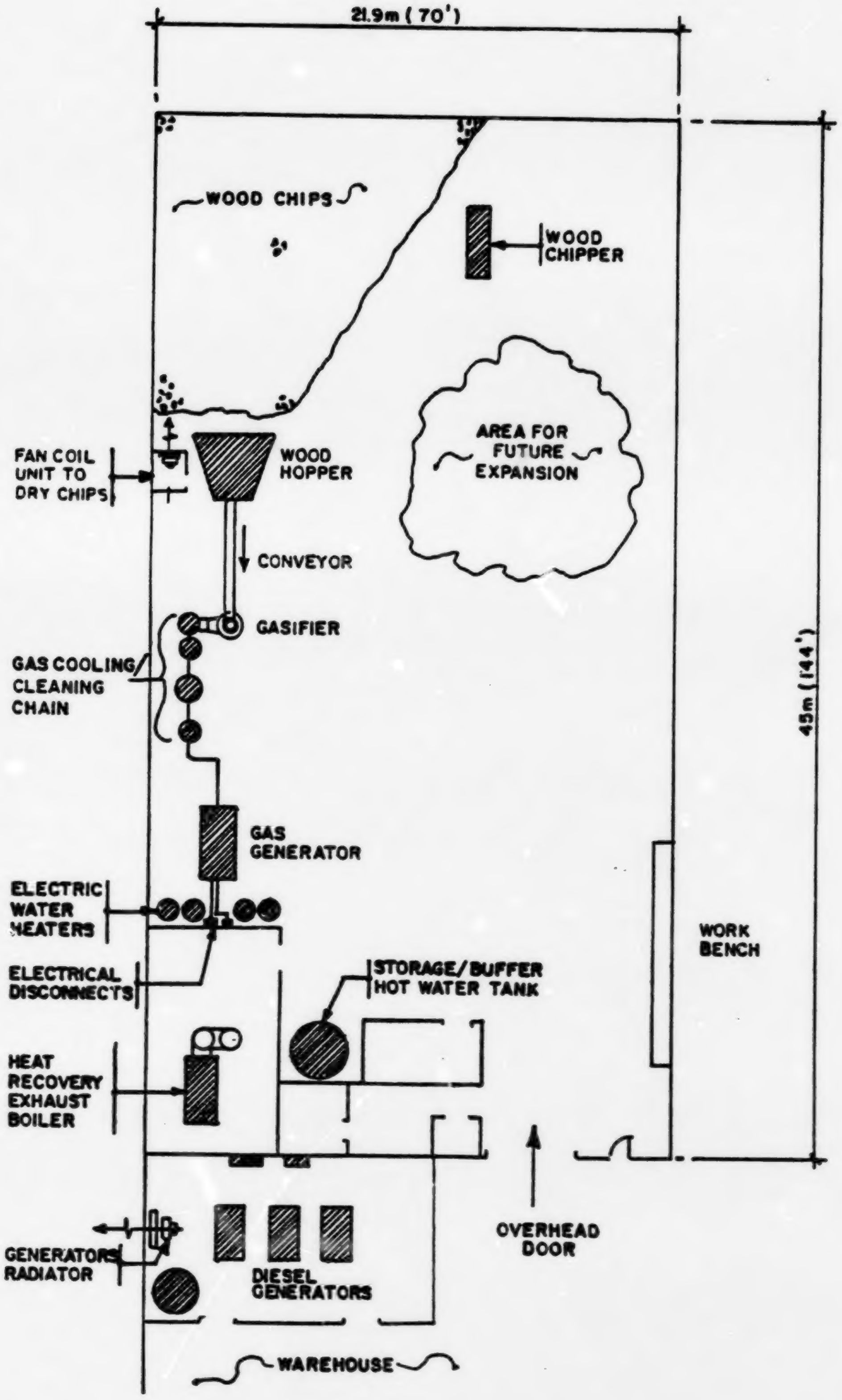
The prime requirement for the source of power generation, is that it is reliable, with minimal power failures. The major conclusion that can be drawn from the past 18 months is that, at this point in time, wood gasification for electrical power generation has not yet reached that desired level of reliability. Even if much more time and money is injected into ironing out the existing problems, the owner is confident that the system would still require 24 hour supervision. As outlined in the "Financial Analysis" section, the additional expense for supervision wages for this scale of plant would then increase the running cost of the gasification system well above that for diesel fuel.

The operating experiences have highlighted problems which, for the most part, have been overcome. The major existing problem is that of unwanted air entering the gasifier during each feeding cycle. This problem is aggravated by the necessity to provide an increased number of smaller feeds to prevent bridging of the wood chips within the airlock. As mentioned in the test report (included as an Appendix) the inrushing air appears to be the major factor in creating engine stalls. A new feeding arrangement is presently being considered, but to date this is an unproven system with no guarantee of totally solving the problem.

The owner is continuing to modify the system. The challenge and determination to overcome the setbacks is great, and the objective to create a smoothly running operation is still a distinct possibility. At that stage, the economics of running a much larger wood gasification plant could become attractive. The advantages of using such a system to provide electrical power to a whole community would include:

: cheaper power for the community
: work for the unskilled labour force in harvesting the necessary wood
: cheaper heating for the community by tapping the waste heat provided by the gasifier and generator engine.
: conservation of the non-renewable resource, oil.

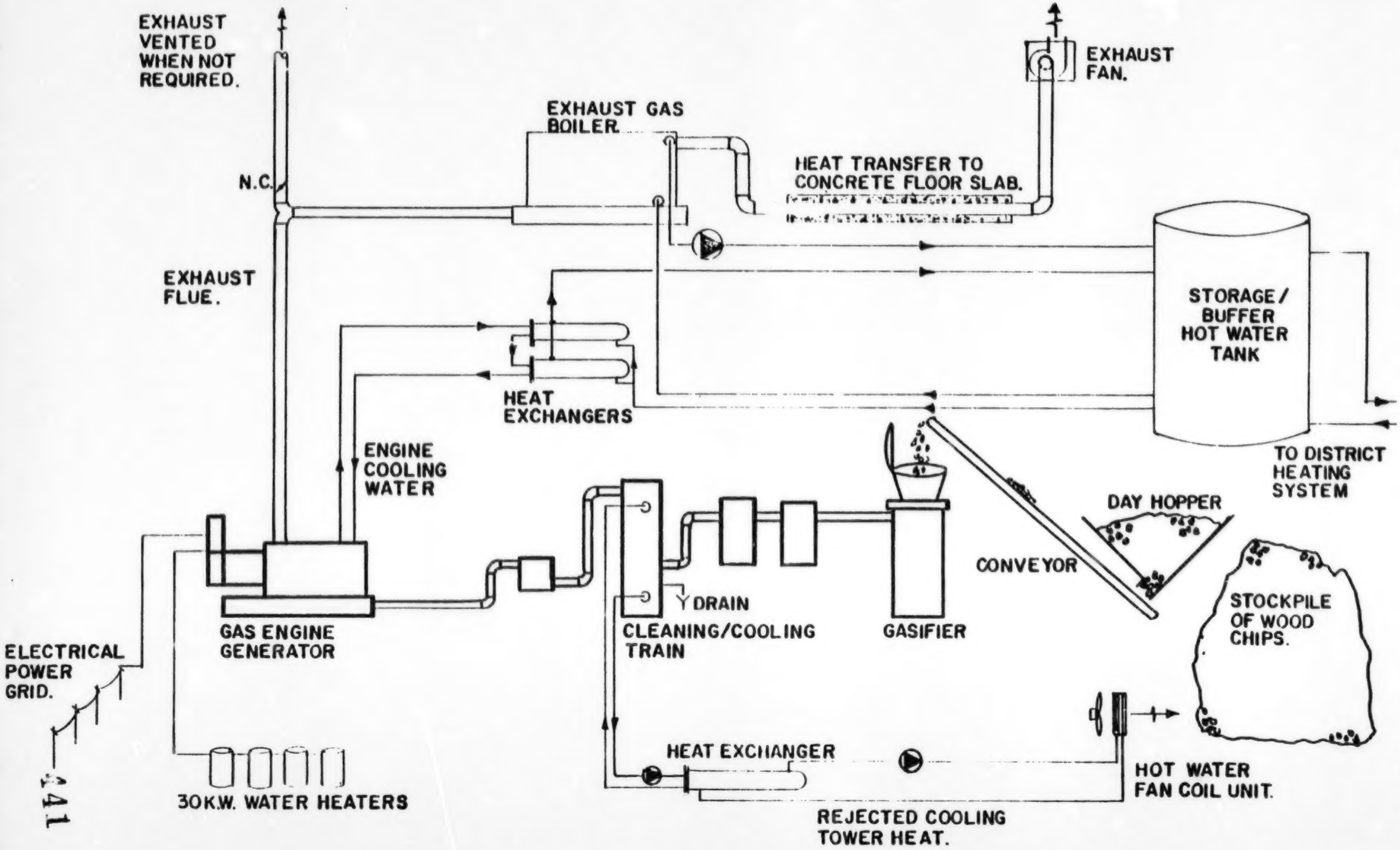
We are not over-optimistic for the future of wood gasification, but if it can be made into a more reliable system, the benefits are clear.



21.9m (70')
45m (144')
WOOD CHIPS
WOOD CHIPPER
AREA FOR FUTURE EXPANSION
FAN COIL UNIT TO DRY CHIPS
WOOD HOPPER
CONVEYOR
GASIFIER
GAS COOLING/ CLEANING CHAIN
GAS GENERATOR
ELECTRIC WATER HEATERS
ELECTRICAL DISCONNECTS
STORAGE/BUFFER HOT WATER TANK
WORK BENCH
HEAT RECOVERY EXHAUST BOILER
OVERHEAD DOOR
GENERATORS RADIATOR
DIESEL GENERATORS
WAREHOUSE

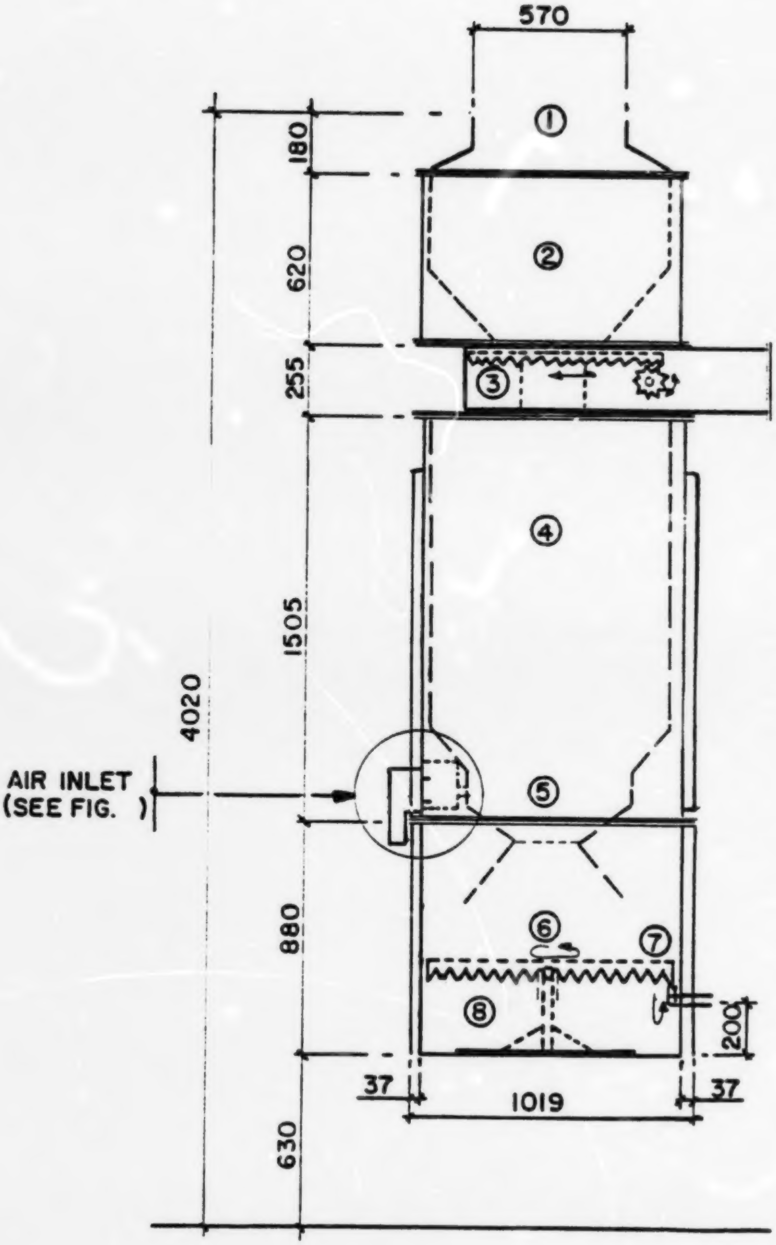
PLAN OF WOOD GASIFIER BUILDING

1:250


EXHAUST VENTED WHEN NOT REQUIRED.
EXHAUST GAS BOILER.
EXHAUST FAN.
HEAT TRANSFER TO CONCRETE FLOOR SLAB.
N.C.
EXHAUST FLUE.
STORAGE / BUFFER HOT WATER TANK
HEAT EXCHANGERS
ENGINE COOLING WATER
TO DISTRICT HEATING SYSTEM
DAY HOPPER
CONVEYOR
DRAIN
GAS ENGINE GENERATOR
CLEANING/COOLING TRAIN
GASIFIER
STOCKPILE OF WOOD CHIPS.
ELECTRICAL POWER GRID.
HEAT EXCHANGER
HOT WATER FAN COIL UNIT.
30K.W. WATER HEATERS
REJECTED COOLING TOWER HEAT.

WOOD GASIFIER SYSTEM SCHEMATIC

① WOOD INLET
② AIR LOCK
③ SLIDING VALVE
④ GASIFIER
⑤ COMBUSTION ZONE
⑥ CHARCOAL/GAS REACTION ZONE
⑦ ROTATING ASH GRATE
⑧ ASH BOX


570
①
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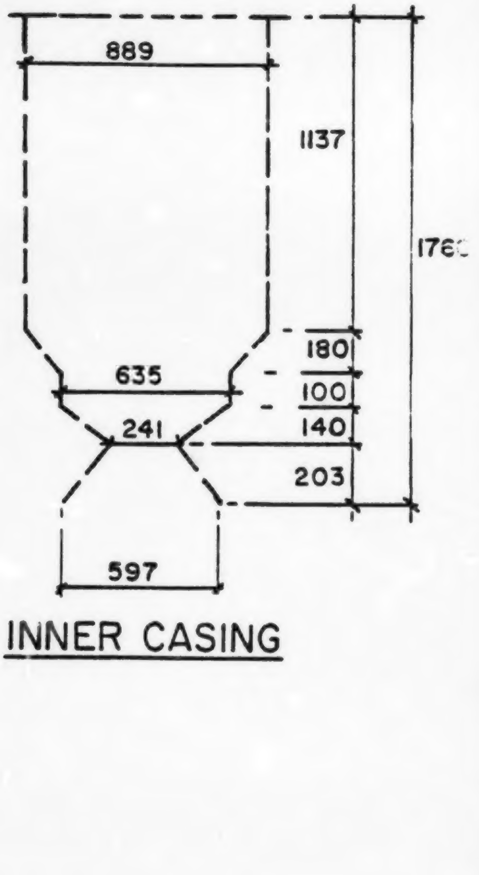
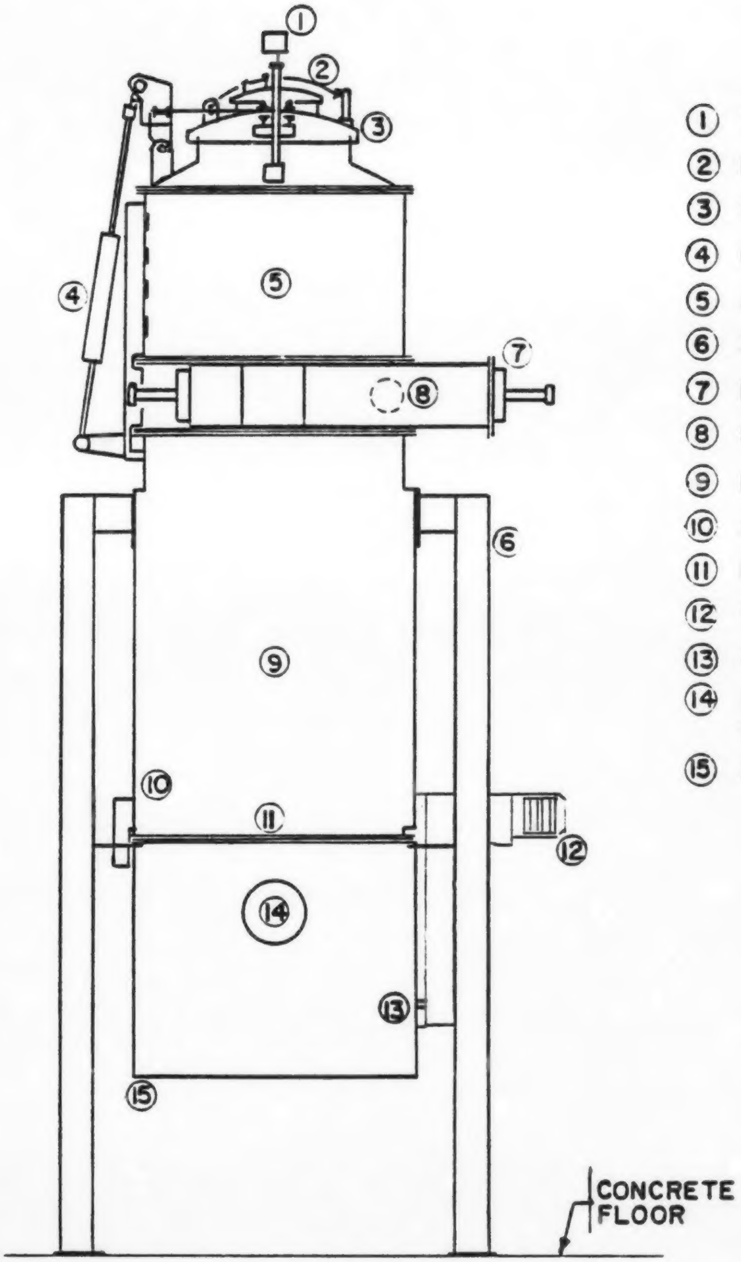
⑥
⑦
⑧
180
620
255
1505
4020
880
630
200
37
1019
37
AIR INLET
(SEE FIG.)


889
1137
176
180
635
100
241
140
203
597

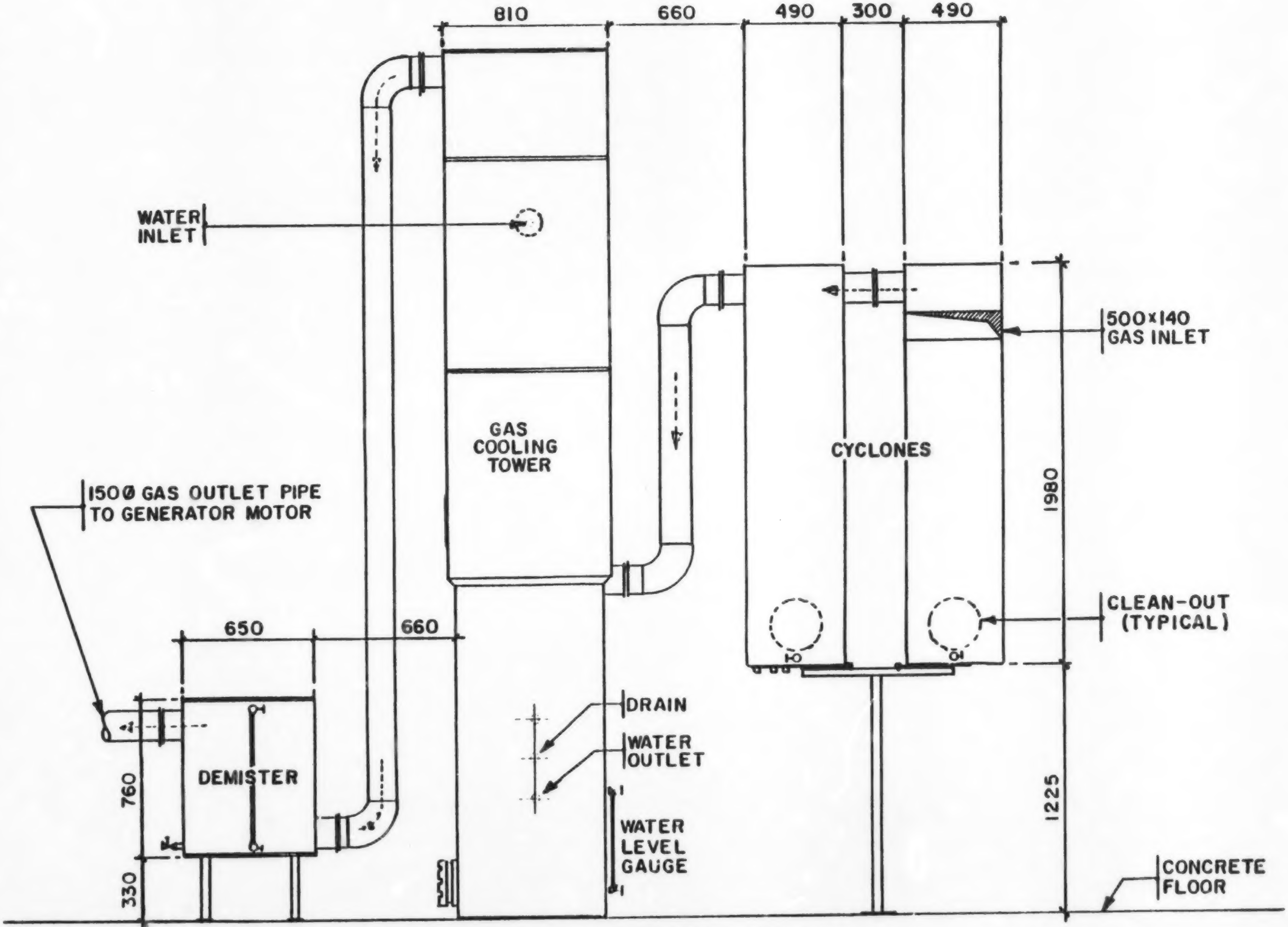
INNER CASING

GASIFIER DIMENSIONS
1:25

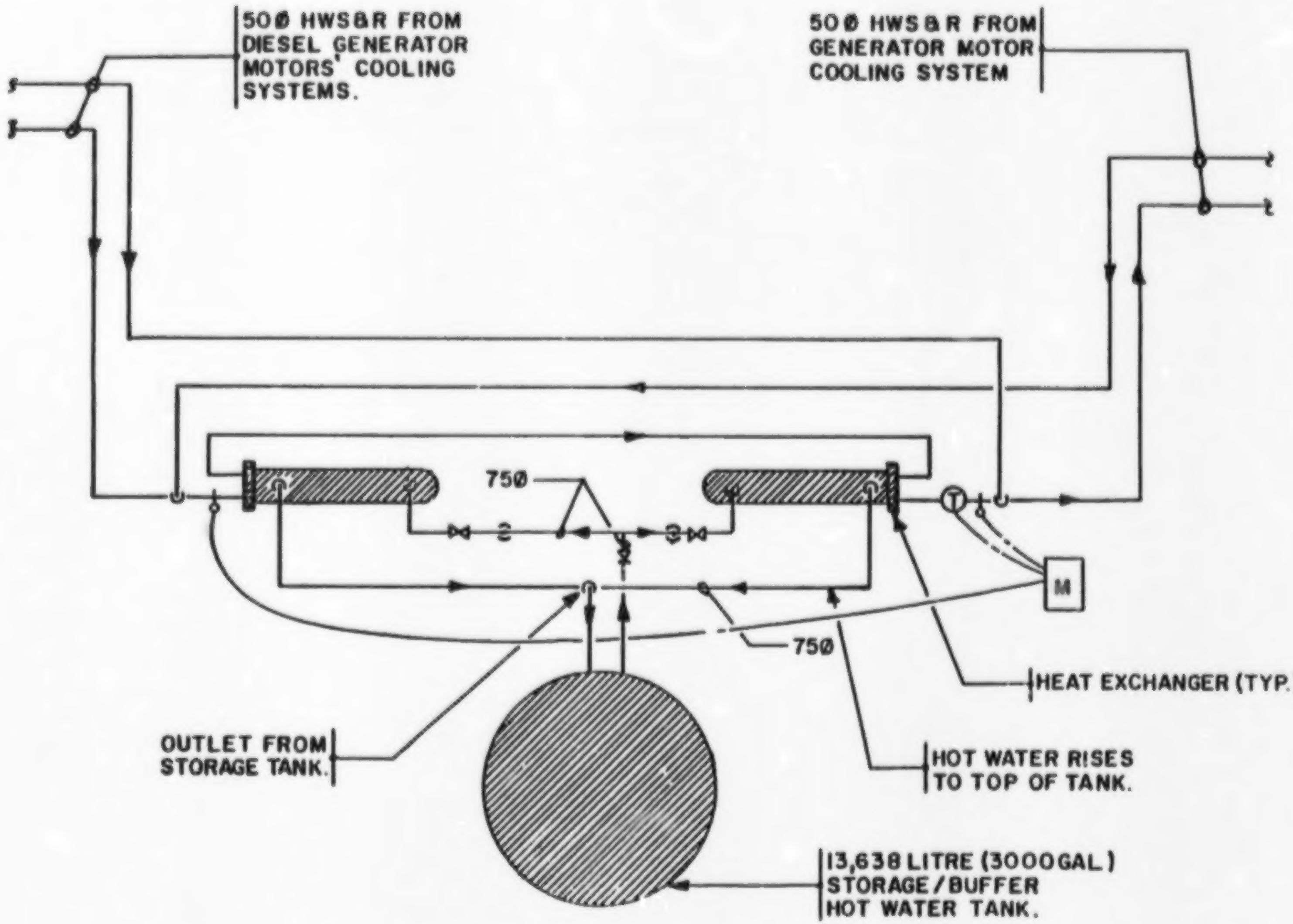


① WOOD LEVEL, PADDLE WHEEL CONTROL
② PRESSURE RELIEF CAP
③ SPRING-LOADED COVER
④ COVER OPERATOR
⑤ AIR LOCK
⑥ SUPPORT
⑦ PRESSURE RELIEF CAP
⑧ SLIDER VALVE MOTOR
⑨ INSULATED CASING
⑩ AIR INLET CHAMBER
⑪ FLANGE C/W ASBESTOS GASKET
⑫ GRATE DRIVE MOTOR
⑬ GRATE DRIVE SPINDLE
⑭ ACCESS TO HEARTH FOR INITIAL CHARCOAL FILL
⑮ AIR INLET SKIRT

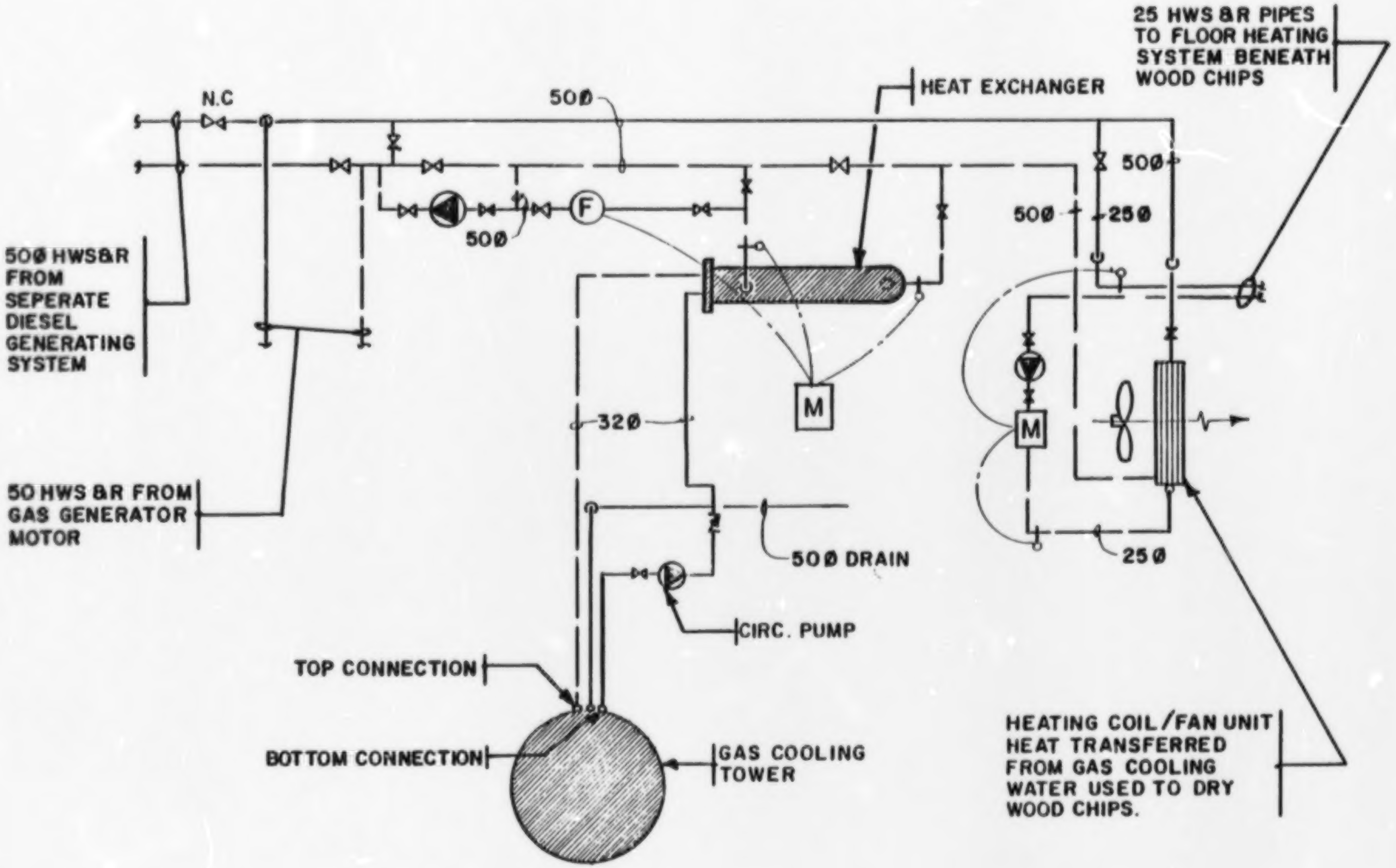
GASIFIER DETAILS
1:25


810
660
490
300
490
WATER INLET
500×140 GAS INLET
GAS COOLING TOWER
CYCLONES
1980
1500 GAS OUTLET PIPE TO GENERATOR MOTOR
650
660
CLEAN-OUT (TYPICAL)
DRAIN
WATER OUTLET
DEMISTER
760
WATER LEVEL GAUGE
1225
330
CONCRETE FLOOR

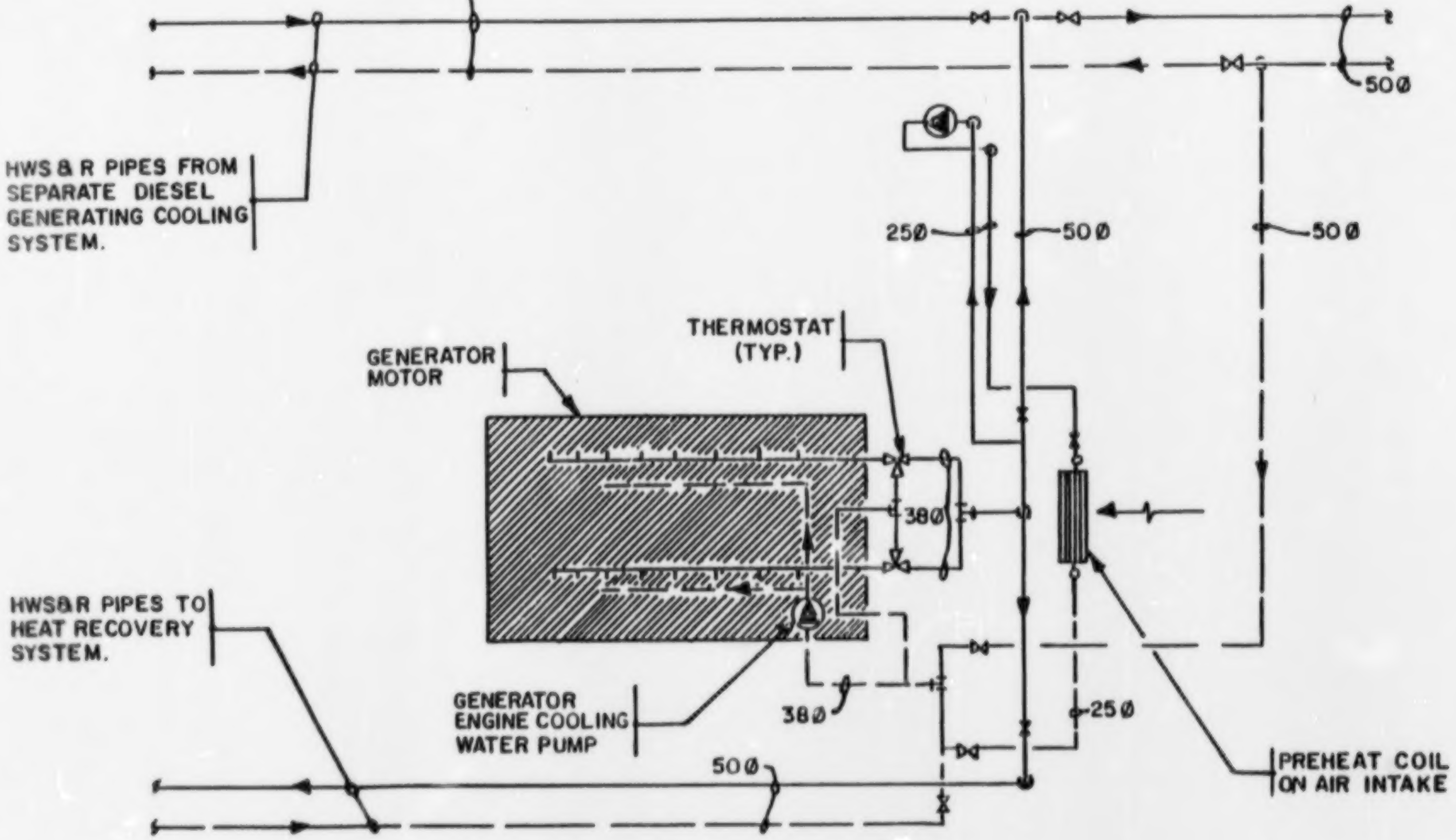
GAS COOLING & CLEANING TRAIN


50Ø HWS&R FROM DIESEL GENERATOR MOTORS' COOLING SYSTEMS.
50Ø HWS&R FROM GENERATOR MOTOR COOLING SYSTEM
75Ø
T
M
75Ø
HEAT EXCHANGER (TYP.)
OUTLET FROM STORAGE TANK.
HOT WATER RISES TO TOP OF TANK.
13,638 LITRE (3000GAL.) STORAGE/BUFFER HOT WATER TANK.

HEAT RECOVERY EXCHANGERS PIPING SCHEMATIC


25 HWS &R PIPES TO FLOOR HEATING SYSTEM BENEATH WOOD CHIPS
N.C
500
HEAT EXCHANGER
500
500
250
500 HWS&R FROM SEPERATE DIESEL GENERATING SYSTEM
500
F
M
M
320
50 HWS &R FROM GAS GENERATOR MOTOR
500 DRAIN
250
CIRC. PUMP
TOP CONNECTION
BOTTOM CONNECTION
GAS COOLING TOWER
HEATING COIL/FAN UNIT HEAT TRANSFERRED FROM GAS COOLING WATER USED TO DRY WOOD CHIPS.

WATER COOLING SYSTEM SCHEMATIC FOR GAS COOLING TOWER


500
HWS & R PIPES FROM SEPARATE DIESEL GENERATING COOLING SYSTEM.
500
250
500
500
THERMOSTAT (TYP.)
GENERATOR MOTOR
380
HWS&R PIPES TO HEAT RECOVERY SYSTEM.
GENERATOR ENGINE COOLING WATER PUMP
380
250
500
PREHEAT COIL ON AIR INTAKE

GENERATOR MOTOR COOLING SYSTEM SCHEMATIC

POOR

QUALITY

ORIGINAL